Resilient Organisations

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A Diagnosis of State Highway Organisations' Decision-Making during Extreme Emergency Events

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Resilient Organisations Research Programme

"Building more resilient organisations, able to survive and thrive in a world of uncertainty, through research and practice"

We live in an increasingly complex world dealing with a broad spectrum of crises arising from both natural and man-made causes. Resilient organisations are those that are able to survive and thrive in this world of uncertainty. Resilience integrates the concepts of Risk, Crisis Management, Business Continuity Planning and Organisational Leadership to provide a platform for developing more robust and agile organisations.

<u>Who we are:</u>
The Resilient Organisations Research Group (ResOrgs) is a multi-disciplinary team of 17 researchers and practitioners that is New Zealand based and with global reach. A collaboration between top New Zealand research Universities and key industry players, including the University of Canterbury and the University of Auckland, ResOrgs is funded by the NZ Foundation for Research, Science and Technology and supported by a diverse group of industry partners and advisors. The research group represents a synthesis of engineering disciplines and business leadership aimed at transforming NZ organisations into those that both survive major events and thrive in the aftermath.

We are committed to making New Zealand organisations more resilient in the face of major hazards in the natural, built and economic environments. Resilient organisations are able to rebound from disaster and find opportunity in times of distress. They are better employers, contribute to community resilience and foster a culture of self reliance and effective collaboration.

<u>What we do:</u>
The ResOrgs programme of public good research is aimed at effective capability building through research activities with significant impacts on policy and practice. The group, in existence since 2004, has hosted an international conference, industry and sector workshops, produced over 30 conference and journal articles and 5 industry reports. These research outputs are already influencing government policy and industry practice. Our growing reputation has already resulted in many collaborations in Australia, the US, Canada and the UK, with a number of requests for the group to participate in a wide range of international projects.

Activities and outputs of the group include informing and focusing debate in areas such as Civil Defence Emergency Management, post-disaster recovery, and the resilience of critical infrastructure sectors, in addition to core activities in relation to organisation resilience capability building and benchmarking. We have produced practical frameworks and guides and helped organisations to develop and implement practical resilience strategies suitable to their environment.

<u>Why we do it:</u>
In an increasingly volatile and uncertain world, one of the greatest assets an organisation can have is the agility to survive unexpected crisis and to find opportunity to thrive in the face of potentially terminal events. We believe such resilience makes the most of the human capital that characterises the modern organisation and offers one of the greatest prospects for differentiating the successful organisation on the world stage. This resilience is typified by 20/20 situation awareness, effective vulnerability management, agile adaptive capacity and world class organisational culture and leadership. More resilient organisations lead to more resilient communities and provide the honed human capital to address some of our most intractable societal challenges.

Executive Summary

This report introduces the development and application of a method to analyse the decision making process of New Zealand's State Highway Organisations (SHO) during extreme events. Building upon our previous research efforts (Dantas et al, 2007 and Ferreira et al, 2008), the aim is to obtain an unbiased and complete overview of the strengths and weaknesses of the current decision making. The report proposes procedures and metrics to analyse the quality of decision making, based upon the study of theoretical and practical concepts of decision making processes.

The method used to analyse the quality of decision making was applied to 3 real events and 4 exercises, which have been observed since 2005. In addition to the real events, the exercises provide a realistic representation of the decision making processes likely to be implemented in the occurrence of extreme events and conditions. Above all, the research team's assessment is that the exercises represented the most likely interaction between MCDEM / Regional Civil Defence / Lifeline groups and NZTA at national, regional and local levels.

The results of the Quality of Decision Making (QDM) analysis indicate that SHO are capable, experienced and competent in dealing with major disruptions or crises that may affect the State Highway Network of New Zealand. SHO have achieved Good and Fair levels of resilience in terms of decision making activities during emergency response events and exercises. Depending on the event or exercise, this means that SHO can:

- Be mostly or partially coordinated;
- Be mostly or limitedly adaptable;
- Be effective or partially effective in most circumstances;
- Provide comprehensive or limited solutions delivery; and
- Provide comprehensive or limited feedback to involved organisations.

Our analysis revealed that SHO performed slightly better in real events than in simulation exercises. The differences in performance are mostly due to the fact that exercises have exposed more junior staff to situations which they do not yet fully understand and/or have the required experience to deploy and coordinate resources allocation.

SHO's major strengths were mostly observed in terms of their ability to perceive, assess and act based on outstanding experience and technical skills. These skills were most often derived from extensive networking (informal and professional) with key individuals involved in emergency response. Senior SHO staff demonstrated high levels of situation awareness and leadership in various situations.

SHO's major weaknesses in terms of decision making during an emergency response are mostly related to resource allocation and information sharing. Most decisions were made without clear and / or rationalised/ structured processes supporting them.

Based on this report's findings a series of recommended initiatives are listed. They comprise:

- An extensive program to address the observed vulnerabilities;
- A continuous program of event and exercise observation;
- Creation of a decision making vulnerability matrix for use in exercise and event debriefs;
- Training package for decision making simulations;
- Standardisation of symbols for maps generated during emergencies;
- A GIS-based information sharing framework; and
- Use of GIS to support simulation exercises.

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1 Introduction

Extreme events present responding organisations with complex and unprecedented situations, and have the potential for catastrophic losses and consequences for communities. In crises and/or emergency events there is an immediate risk to life, health, property or environment (Vedder, 1990; Fink, 1986; Berroggi and Wallace, 1995). Thus, organisations have to quickly respond to observed and changing conditions. These are usually different to what personnel are used to dealing with on a daily basis, under business-as-usual situations (Fredholm, 1999).

There is limited understanding of how organisations make decisions in extreme events. However a few studies have been observed in recent years which provide empirical evidence that decision makers are impaired by the complexities observed in real situations. (Zografos *et al.*, 2000; Mendonça *et al.,* 2001; Mendonça, 2005; Sinha, 2005; Mendonça *et al.*, 2006; Mendonça and Wallace, 2007), It is also often observed through anecdotal evidence that decision makers use their own experience and common sense in order to respond to events.

A particular and critical element of response to extreme events is the roading network. Recent worldwide events (e.g. Northridge Earthquake, 1994; Sumatra Earthquake and Tsunami, 2004) have demonstrated that the functionality of road transport networks to respond to emergencies is vital in saving lives and reducing economic impacts. Many organisations depend on road transport to conduct their own response activities (AELG, 2005). Under the New Zealand Civil Defence Emergency Management Civil Defence Emergency Management (CDEM) Act 2002, road transport networks, along with other key lifeline utilities are expected to function to the fullest possible extent during and after an emergency event.

This report introduces the development and application of a methodology to analyse the decision making process of New Zealand's State Highway Organisations (SHO[1]) during extreme emergency events. Building upon our previous research efforts (Dantas *et al*, 2007 and Ferreira *et al*, 2008), the aim is to obtain an unbiased and complete overview of the strengths and weaknesses of the current decision making. This report also proposes procedures and metrics to analyse the quality of decision making, based upon the study of theoretical and practical concepts of decision making processes.

This report is divided into six sections. The next section presents a conceptual framework to enable observation of decision making activities. The third section describes the method used to analyse decision making performance. The fourth section introduces the application of the observation framework and the Quality of Decision Making (QDM) analysis method to a series of case studies in which SHO are the main subject. The fifth section presents the analysis of SHO decision making processes. Finally, the sixth section presents the conclusions and recommendations which are drawn from the application of the analysis method and the whole experience of observing decision making processes in New Zealand.

[1] SHO comprise New Zealand Transport Agency (NZTA) and its regional contractors and consultants.

2 Observation Framework

This section presents an observation framework for the analysis of decision making quality for real or simulated events. Using the scheme proposed by the Defence Command and Control Research Program, (CCRP) model (Cheah et al., 2000) as the main reference, this framework focuses on three key elements: 1) situation awareness; 2) good quality of information sharing; and 3) decision makers' expertise and experience. Four interconnected domains of decision making are targeted; they include:

- ***Physical domain*** is the tangible real world where physical and human resources are moved through time and space to attend the range of operations required to respond to the evolving extreme event. The physical domain is also the space where organisations and the physical and communications networks that connect all of the organisations involved in the management of the extreme events reside;

- ***Information domain***is the abstract space where information exists and is collected, created, processed, manipulated, and shared and from where information content and flow are created. The quality of the information depends on the accuracy, timeliness, and relevance of information from all sources. The information domain is the link between the reality of the physical domain and human perceptions, therefore it is formed by the intersection of the physical and cognitive domains;

- ***Cognitive domain***is identified within the mind of the decision-makers, where individual and organisational collective consciousness exists, where decision maker's knowledge, capabilities, techniques, and procedures reside; and

- ***Social domain***is the domain where humans interact, exchange information, form shared awareness and understanding, and make collaborative decisions. This is also the domain where culture, values, attitudes, and beliefs are conveyed by leaders to society. The social domain overlaps with the information and cognitive domains, but it is distinct from both. Cognitive activities, by their nature, are individualistic; they occur in the minds of individuals. In contrast, shared awareness and shared sense-making (the process of going from shared awareness to shared understanding to collaborative decision making) are by definition, a socio-cognitive activity because the individual's cognitive activities are directly impacted by the social nature of the exchange and vice versa.

These domains are linked to decision making tasks and cognitive elements. The next sub-section presents the explanation of each of the decision making tasks and cognitive elements. This is followed by the description of the success indicators and vulnerabilities associated with each observation domain.

2.1 Decision making tasks and cognitive elements

In order to evaluate the decision making process, it is important to identify the key elements under observation. In this case, the elements under observation are the activities of roading organisations faced with extreme events or crises. Specific tasks and sub-tasks associated with the Physical and Information domains are listed in Table 2.1. In the same way, specific cognitive and sub-cognitive elements can be depicted for the Cognitive and Social domains. The observation framework proposed in Table 2.1 is not intended to be a rigid reference.

Alternative and more suitable tasks and cognitive elements can be identified and specified depending on the event under observation. Importantly, the tasks and sub-tasks, as well as the cognitive and sub-cognitive elements, are not likely to occur independently of the main tasks. It is acknowledged that functions of a decision making process are always accomplished concurrently and interactively.

Table 2.1 -Tasks/sub-tasks to be observed, cognitive/sub-cognitive elements to be investigated during the decision making process

Domains of DM	Tasks	Sub-tasks	Acronyms
PHYSICAL	***Response Actions***	Deployment of human resources	**DHR**
		Deployment of physical resources	**DPR**
		Temporary traffic management	**TTM**
		Damage assessment and management	**DAM**
INFORMATION	***Data Processing***	Data collection	**Data C**
		Data analysis, storing, summarising	**Data A**
		Data sharing, disseminating	**Data S**
		Data maintaining, updating	**Data U**
	Communication	Communication intra-organisations	**C_INTRA**
		Communication inter-organisations	**C_INTER**
		Communication with media	**C_MEDIA**
		Communication with public	**C_PUBLIC**
Domains of DM	**Cognitive Elements**	**Sub-Cognitive elements**	
COGNITIVE	***Situation Awareness***	Perception of the evolving scenario	**Perception**
		Understanding of needs	**Understanding**
		Projection of future	**Projection**
SOCIAL	***Collaboration and Coordination***	Collaboration intra-organisations	**S_ INTRA**
		Collaboration inter-organisations	**S_ INTER**

2.2 Success indicators and vulnerabilities

Specific success indicatorsare identified for each of the decision making domains. They are:

- **Physical Domain** (S_P): optimisation of actions to ensure that the road network is able to function to the fullest possible extent, even though this may be at a reduced level, during the emergency and in the recovery and reconstruction phases. These include:

  S_{P1}) minimisation of road closures, duration and variability;
  S_{P2}) maximisation of accessibility to strategic services and places; and
  S_{P3}) minimisation of response and recovery costs

Theses success indicators can be assessed by quantifying post-emergency phase costs and the time required to complete the response and recovery phases to the emergency/crisis event, or by judging qualitatively the identification of priorities and resource allocation.

- Information Domain (S_I) measures the degree of connectivity achieved between the various decision makers in a network-enabled environment and the quality of the information exchanged. These include:

S_{I1}) the degree of connectivity achieved;
S_{I2}) the information richness; and
S_{I3}) the extent of information reach.

The degree of connectivity between the various decision makers can be assessed qualitatively by investigating the characteristics of the interactions between decision makers. Similarly, the information richness can be assessed qualitatively, as a function of the degree of sharing of various forms of information – visual, audio, multimedia, and tools (Albert and Hayes, 2003). Finally, the extent of information reach can be assessed along the dimensions of whether it facilitates simultaneous, selective, and universal communication.

- Cognitive Domain (S_C) focuses on a judgement of the decision-makers behaviour in order to understand the decision maker's knowledge, capabilities, techniques, and procedures. These comprise:

S_{C1}) the individual situation awareness;
S_{C2}) the level of training and experience; and
S_{C3}) intangibles of leadership and unit cohesion.

Individual situation awareness can be investigated by using ad-hoc questionnaires or interviews targeting the assessment of the perception of evolving scenarios, the understanding of needs, demands and implications and the participants' projection of the future. Codified techniques such as the Situation Awareness Global Assessment Technique, SAGAT (Endsley, 1995a and Endsley, 1995b) might also be adapted to suit the needs of the assessment.

- Social Domain (S_S) includes the responsiveness to the needs of emergency management agencies and the technical advice provided to leading emergency management agencies and lifeline groups. These include:

S_{S1}) responsiveness to the needs of emergency management agencies;
S_{S2}) technical advice to leading emergency management agencies and lifeline groups; and
S_{S3}) coordination of actions with all involved agencies.

The level of responsiveness and technical advice provided to emergency management agencies and lifelines groups can be assessed based on expert judgment after the observation phase. The coordination of actions with all involved agencies can be assessed by quantifying the level of self-synchronisation and team collaboration that is achieved. Self-synchronisation is the capability of junior staff to operate autonomously when appropriate. This involves re-tasking themselves through sharing awareness to achieve strategic and operational objectives in accordance with the high level decision maker's intent. Self-synchronisation can be investigated by critically analysing the different types of communication exchanged between different levels of decision makers. In the context of roading organisations, self-synchronization is investigated by analysing whether or not contractors and consultants are able to work out the details of their response activities as new information about the external situation becomes available, without having to continuously rely on decision makers to provide specific directions. Team collaboration measures the degree and quality of collaboration between various team members and can be inferred from the analysis of messages exchanged during the decision-making process. This focuses on information, action and coordination requests and transfers (frequency counts and the ratio of transfers to requests) and on the communication check.

Tangible and intangible vulnerabilities affecting the fulfilment of the decision making success indicators are identified and recorded. For the sake of simple data processing and analysis, observed tangible and intangible vulnerabilities are annotated in a matrix. Tables 2.2 and 2.3 show examples of how physical and information vulnerability matrices would be populated for an event. As shown in Table 2.2, the example represents an event in which deployment of human resources (DHR), deployment of physical resources (DPR) and damage asset management (DAM) were observed. For each observed task and/or subtask, comments on observed tangible and intangible vulnerabilities are also recorded. For example, amongst all other vulnerabilities, it is noted that no standardised damage survey form was created for the DAM task (Table 2.3).

Table 2.2 –Example of decision making vulnerability matrix for the Physical Domain.

PHYSICAL DOMAIN

S_{P1}*- Minimisation of road closures duration and variability*

Task/Sub-tasks				***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
DHR	**DPR**	**TTM**	**DAM**		
☑	☑	-	-	Insufficient Resources	
-	☑	-	-		Lack of Situation Awareness about available resources
-	-	-	☑	No standardised damage survey form	

Table 2.3 –Example of decision making vulnerability matrix for the Information Domain.

INFORMATIONDOMAIN

S_{I1}*- Level of Connectivity*

Task/Sub-tasks				***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
INTRA	**INTER**	**MEDIA**	**PUBLIC**		
☑	☑	-	-	-	Poor degree of interactivity

S_{I2}*- Information richness*

INTRA	**INTER**	**MEDIA**	**PUBLIC**	***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
☑	☑	-	-	Technical problems limiting the information sharing in visual form via voice or multimedia transmissions	-
☑	☑	-	-	Absence of supporting tools like Geographical Information System, or Decision Support System.	-

S_{I3}*- Information reach*

INTRA	**INTER**	**MEDIA**	**PUBLIC**	***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
☑	☑	-	-	Unavailability of a dedicated terminal for each decision maker for accessing the information.	Lack of simultaneity (decision makers unable to receive the content being shared at about the same time)
☑	☑	☑	-	Instability of the adopted communication system, where various participants lose connectivity to the network at different times	Lack of selectivity (impossibility to selectively choose who to send out text messages to

3 Quality of Decision-Making (QDM) Analysis Method

The QDM method aims to evaluate roading organisations' decision making processes during extreme emergency events. An excellent resilience level has been achieved if the following characteristics are observed:

- ***timely*** - able to make rapid decisions in the face of severe consequences; able to act within windows of opportunity;
- ***robust*** - effective across a variety of circumstances in order to allow for changes in situations; able to operate under highly stressful conditions without suffering degradation in performance and permitting recovery from missteps or adversity arising from a lack of full understanding;
- ***adaptive*** - able to engage in a continuous process of strategy assessment and modulation, permitting changes in both processes and organisation as information is gained about the complex situation; able to cope with an ambiguous, rapidly changing and complex environment and able to provide more than one way to achieve success;
- ***effective*** - able to deliver solutions that are as close to ideal as possible, despite the stress, time pressure, level of risks and complexity of the decision making situation; able to effectively judge and manage higher levels of risk by using knowledge and experience to conduct risk assessments; and
- ***learning*** - actively learns from feedback about the complex situation which result in observable changes of behaviour where required; able to react quickly and effectively, as decision makers learn what works and what does not and what is counterproductive, and able to change approaches as the complexity of the situation changes.

QDM uses decision making assessment matrices as visual tools in which success indicators of different decision making domains are represented. The matrices are populated based upon processing qualitative or quantitative information previously recorded.

The matrices are populated by considering the following items:

- **Applicability:** identify whether or not a success indicator is relevant to the specific decision making process under analysis;

- **Performance Level:** report the suitability and quality achieved in performing the different sub-tasks. For each i-th sub-task/sub-cognitive element pertinent to a certain j-th success indicator within the analysed domain d,a performance levels $P_{i,j,d}$ is assigned using a five-level qualitative scale:

  Poor ($0 < P_{i,j,d} \leq 1$);
  Limited ($1 < P_{i,j,d} \leq 2$);
  Fair ($2 < P_{i,j,d} \leq 3$);
  Good ($3 < P_{i,j,d} \leq 4$); and
  Excellent ($4 < P_{i,j,d} \leq 5$).

A zero score, corresponding to a Non Performed condition $P_{i,j,d}$=0 is also available. Table 3.1 shows the suggested qualitative scale for measuring the performance levels.

- **Degree of fulfilment:** assess the performance level achieved for each success indicator, based on observed sub-tasks and sub-cognitive elements. Mathematically, the degree of fulfilment $F_{d\,j,}$is evaluated combining, according to a weighted average, the performance levels$P_{i,j,d}$ attributed to the sub-task/cognitive elements pertinent to the *j-th*success indicator.

$$F_{dj} = \sum_{i=1}^{t} \alpha_i P_{i,j,d} \qquad \text{(Eq. 3.1)}$$

where α_i is a normalised weight associated to the *i-th*sub-task/cognitive element pertinent to a *j-th* success indicator;referred to as **sub-task/cognitive elements normalised weight**. The normalised weighted average allows accounting for the different proportional relevance that each sub-tasks/cognitive element could have in the fulfilment of a certain success indicators.

- **Decision domain global score:** compute a global score representing the quality of the decision making process pertinent to the specific domain. The decision domain global scoreD_d is computedcombining, according to a normalised weighted average, the degree of fulfilment $F_{j,d}$ evaluated for the success indicators pertinent to the domain D_d according to Equation 3.2.

$$D_d = \sum_{j=1}^{r} \beta_j F_{j,d} \qquad \text{(Eq. 3.2)}$$

where β_j is a normalised weight associated to each success indicator *j-th*pertinent to the domain *d* and referred to as **success indicator normalised weight**.The normalised weighted average allows for the different proportional relevance that each success indicator could have in the quality achievement of a certain domain.

Finally, a global score for the decision making quality is measured combining the scores evaluated for the 4 different domains, as follows:

$$DM = \sum_{d=1}^{4} \gamma_d D_d \qquad \text{(Eq. 3.3)}$$

where γ_d is a normalised weight associated to each domain D_d and referred to as **success indicator normalised weight**. The normalised weighted average accounts for the different proportional relevance that each domain could have in the global quality of decision making process under different circumstances.

Tables 3.1 and 3.2 provide an example of Assessment Matrices populated for the analysis of the Physical and Information Domains in the decision making process. The expert judgment on the performance level achieved for the different sub-task/cognitive elements takes into account tangible and intangible vulnerabilities annotated in Tables 2.2 and 2.3. For example, the “Minimisation of the road closures duration and variability” is identified as the only success indicator targeted during the decision making process in the Physical Domain Matrix. Toward the attainment of this goal, temporary traffic management (TTM) was performed at a “fair” level; the deployment of human resources (DHR) and the management of the damage assessment (DAM) were performed at a “limited” level; while the deployment of physical resources (DPR) was performed at a “poor” level.

The normalised weight, α_i varies assuming a higher importance for the sub-taskDPR and DHR, α_{DPR} =0.35 and α_{DHR} =0.25 respectively, and lower importance for the sub-tasks TTM and DAM α_{TTM}=α_{DAM}=0.15.

The values of the sub-task normalised weight, α_i are supposed to be defined before the implementation of the QDM analysis through liaising with decision-makers. Sub-task weights accounts for issues that can influence the decision making processes such as pre-defined strategies and priorities, expectations from end-users and other responding organisations, resources availability, organisation’s role, etc. Multi-criteria analysis approaches can effectively support the process of priority and expectation identification and weighting (Ferreira et al., 2009).

Table 3.1 - Assessment Matrix for the analysis of the Physical Domain in the decision making process.

PHYSICAL DOMAIN		Applicability	Performance Level				β	Degree of Fulfilment
SUCCESS INDICATORS	*S_{P1}) Minimisation of road closures duration and variability*	☑	2	1	3	2	**1**	1.6
	S_{P2}) Maximisation accessibility to strategic services and places	☐	-	-	-	-	-	-
	S_{P3}) Minimisation response and recovery costs	☐	-	-	-	-	-	-
			DHR	**DPR**	**TTM**	**DAM**		**D_P**
		α	**0.30**	**0.40**	**0.15**	**0.15**		1.6
			SUB-TASKS					

Applicable: Yes ☑, No ☐

Level of Performance					
5	Excellent				
4	Good				
3	Fair				
2	Limited				
1	Poor				

Table 3.2 - Assessment Matrix for the analysis of the Information Domain in the decision making process.

INFORMATION DOMAIN		Applicable	Performance Level				β	Degree of Fulfilment
SUCCESS INDICATORS	S_{I1}) *Connectivity*	☑	3	2	4	4	0.6	1.95
	S_{I2}) *Information richness*	☑	1	1	2	2	0.25	0.38
	S_{I3}) *Information reach*	☑	1	1	2	3	0.15	0.26
			INTRA	INTER	MEDIA	PUBLIC		D_I
		α	0.25	0.25	0.25	0.25		
Applicable: Yes ☑, No ☐			SUB-TASKS					2.59

Level of Performance	5	Excellent	4	Good	3	Fair	2	Limited	1	Poor

Accounting for the different values, the Physical Domain results $F_{1,1}=2$, according to Equation 3.1. Assuming that it was not possible to observe and judge theother two success indicators of the Physical Domain, their degree of fulfilment results in $F_{2,1}= F_{3,1}=0$. According to Equation 3.2, and setting necessarily β_1=1, the performance of the Physical Domainhas been judged “limited”, with the Physical Domainglobal scoreresulting in, D_P=1.6.

The same evaluation is performed for the Information Domain Matrix. In this case the same proportion of relevance has been assumed for all the sub-tasks pertinent to the Information Domain, $\alpha_i=0.25$. Accounting for the performance levels attributed to the different sub-tasks, and implementing Equation 3.1, the success indicators of the Information Domain are targeted with a degree of fulfilment respectively corresponding to $F_{1,2}=3.25$, $F_{2,2}=1.5$, $F_{3,2}=1.75$ for connectivity, information richness and information reach. It is worth noting that, differentproportion relevance for the three success indicators have been hypothesised as shown in Table 3.2 where the fulfilment of the information connectivity has been assigned a higher importance. According to Equation 3.2, the performance of the Information Domain within the decision making process, is judged as “fair” corresponding to D_I=2.59.

Table 3.3 summarises the results of the performance observed for all of the domains and provides the values assumed for decision making domain weights. The Physical and Information domains are supposed to be of the same proportional relevance, toward the attainment of a good quality decision making process, therefore $\gamma_P=\gamma_I=0.5$. Given the Social and Cognitive Domains were not observed, the sum in Equation 3.3 is computed considering only the results obtained for the Physical and Information Domains (d=1÷2 in Equation 3.3). The quality of the observed decision making reaches a “fair” level, globally resulting in DM=2.09.

Table 3.3 - Visual representation of the performance levels observed for the decision making domains.

Physical	D_P	D_C	Cognitive
$\gamma_P=0.5$	1.6	-	-
$\gamma_I=0.5$	2.59	-	-
Information	D_I	D_S	**Social**

Using the decision domains (D_d) and global score (DM) obtained respectively through Equations 3.2 and 3.3, a roading organisation can assess, on one hand its performance relative to each single domain and, on the other hand, its performance relative to the overall decision making process.

A five-level qualitative scale has been applied to categorise the performance of the decision making process in terms of:

- Poor Resilience (0<DM≤1);
- Limited Resilience (1<DM≤2)
- Fair Resilience (2<DM≤3)
- Good Resilience (3<DM≤4), and
- Excellent Resilience (4<DM≤5).

Table 3.4 shows the graphical output of the QDM analysis method. Attributes summarising the strengths and weaknesses affecting the single domain and the overall decision making processes of the organisation have been identified for each of the five levels identified (Table 3.4). According to the assumed scale, the decision making process of an organisation that achieves a global score DM=1.42 is classified as “Limited Resilience”, which means that the organisation is/has:significant dysfunction; very limited adaptability, not effective in many circumstances, very limited in solutions delivery; very limited feedback to involved organisations.

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Table 3.4 - Visual representation of the performance levels observed for the decision making

		Levels of Performance	(D_d / DM scores)			
		Poor Resilience (0-1)	**Limited Resilience (1-2)**	**Fair Resilience (2-3)**	**Good Resilience (3-4)**	**Excellent Resilience(4-5)**
DOMAINS	**P**	- No optimisation consideration	- Limited efforts to improve resources allocations	- Significant efforts towards optimisation	- Minimization of road closures - Maximization of accessibility - Minimization of costs	- Dynamic minimization and maximization efforts
	I	-No connectivity amongst organisations	- Casual connections with limited information exchange	- Informal and formal connections - Limited coverage - No information sharing standards	- Comprehensive connections - Extensive coverage - Information sharing standards adopted	- Long-standing connections - Full coverage - Dynamic information sharing practice
	C	- No situation awareness	- Limited individual awareness	- Individual awareness - Limited training and experience	- Individual awareness - High levels of training and experience - Limited leadership and cohesion	- Individual awareness - High levels of training and experience - High levels of leadership and cohesion
	S	- No responsiveness to others	- Very limited responsiveness to emergency management (EM)agencies	- Partial responsiveness to EM agencies - Limited technical advice provided	- High level of responsiveness to EM agencies - Comprehensive technical advise - Limited coordination	- Total responsiveness to EM agencies - Accurate and timely technical advise - Full coordination
OVERALL		- Dysfunctional; - No adaptability; - Not effective in most circumstances; - Severely limited in solutions delivery; - No feedback to involved organisations	- Significantly dysfunctional; - Very limited adaptability - Not effective in many circumstances - Very limited in solutions delivery; - Very limited feedback to involved organisations	- Adequate but with some dysfunctionality; - Limited adaptability - Not effective in all circumstances - Limited in solutions delivery; - Some feedback to involved organisations	- Mostly coordinated - Mostly adaptable - Effective in most circumstances - Comprehensive solutions delivery; - Comprehensive feedback to involved organisations	- Timely - Adaptive - Robust - Adaptive - Effective - Learning-oriented

4 Case Studies

The QDM analysis method proposed in section 3 is used to study how SHOs (New Zealand Transport Agency (NZTA[2]), its consultants and contractors) set priorities and make decisions during response and recovery to extreme emergency events. Both real events and emergency management exercises involving SHOs in New Zealand have been observed and assessed since 2004.

The observation of events and exercises follows a three-step process, as shown in Table 4.1.

1. Step 1 comprises knowledge elicitation, including the observation of the decision making process and the development of descriptive accounts of the events/exercises.

2. Step 2 entails debriefs including in-depth interviews with subject matter experts. This aims to identify the cognitive elements that underlie goal generation, decision making and judgements. Debrief and interview activities focus on gaining information to analyse situation assessment strategies, identification and interpretation of critical cues, patterns and meta-cognitive strategies.

3. Step 3 includes the analysis and process of acquired data/information in order to implement the QDM analysis method.

Table 4.1 - Activities and expected outcomes for the three-step method proposed for the analysis of extreme events decision making.

Step		Activities	Expected Outcomes
1	*Knowledge Elicitation*	Observation of decision making process during real and simulated extreme events and tracing of the decision making stories	Comprehensive understanding of the real or simulated event scenario and qualitative assessment of tangible/intangible vulnerabilities affecting the decision making
2		Debriefs and in-depth interviews with subject matter experts following real and simulated events	Identification of the cognitive elements and underlying decision making
3	*Analysis and Knowledge Representation*	Extracting meanings from the acquired data and information and displaying the results	Assessment of strengths and weaknesses underlying the decision making process

[2] NZTA refers to the amalgamation of Land Transport New Zealand and Transit New Zealand, which occurred in 2008.

Characteristics of observed real events and simulation exercises

This section summarisesthe characteristics of four simulation exercises (Table 4.2) and three real events (Table 4.3) involving SHOsobserved since 2004.

The occurrence of a major earthquake was the most common scenario adopted during exercises. Only one exercise considered the occurrence of a tropical cyclone (Marconi Exercise) and another presented the occurrence of a major volcano eruption in the Auckland area. The observed sample has mainly included two types of exercise (tabletop and functional) and a significant variety of levels of organisational involvement (international, national, regional and single organisation). Only one observed exercise was classified as a table-top exercise (Marconi Exercise organised by the Auckland Lifelines Group) while all the others have been identified as functional exercises.

Due to resource limitations, it was only possible to directly observe the consultants and contractors actions and decision making procedures in the Icarus exercise. For all other exercises, only the activities of NZTA were observed. From our analysis, we conclude that consistently satisfactory decision making was observed during the exercises. Our research team's assessment is that these exercises, although necessarily a simplification of the conditions of a real extreme event, provide a good indication of the likely interactions between MCDEM./ Regional Civil Defence / Lifeline groups and NZTA at national, regional and local levels.

Table 4.2 - Characteristics of observed simulation exercises.

Name Date Location	*Simulated Event*	*Exercise Typology*	*Aim*	*Observed Organisations*
Capital Quake 14th and 15th November 2006, Wellington	major earthquake in Wellington	national civil defence functional exercise organised by the MCDEM	test New Zealand's all-of-nation arrangements for responding to a major disaster	NZTA Regional Office, Wellington
Marconi Exercise 8th June 2007 Auckland	tropical cyclone causing significant damage and flooding in the Auckland Region	distributed tabletop exercise organised by the Auckland Engineering Lifelines Group	lifeline utility co-ordination processes in the Group EOCwith focus to information transfer	NZTA Northcote Traffic Management Centre (ATTOMS Centre) Auckland
Icarus Exercise 22nd November 2007 Wellington	major earthquake in Wellington	Functional exercise as part of the NZTA scheduled annual training	train staff in their roles within EOC (Emergency Operations Centre); practice allocation and communication between organisations; test aerial reconnaissance arrangements between NZTA and Greater Wellington Regional Council (GWRC)	NZTA Wellington Regional Office, Consultants one contractor and the GWRC
Ruamouko Exercise 13th March 2008 Auckland	volcano eruption in Auckland	Tier 4 national-level functional exercise in accordance with the MCDEM National Exercise Programme (joint local government and central government exercise, Auckland CDEM Group, MCDEM, DPMC)	test New Zealand's all-of-nation arrangements for responding to a major disaster with particular focus on roles and responsibilities, arrangements and connections between, local, regional, national and international agencies	NZTA National Office in Wellington, GEOC Auckland, GEOC Wellington, ATTOMS Centre, Waitakere EOC

Table 4.3 - Characteristics of observed real events.

Name Date Location	*Summary Event Description*	*Organisations Observed*
Ruapehu Volcanic Eruption 25th of September 2007	A 2.9 Earthquake occurred on the night of the 25th September that triggered a number of response actions from NZ Police and a local contractor. The response included the evacuation of sixty people from Aorangi and Ruapehu huts, closing ski fields on the 26th September and assessing damage at State Highways surrounding the Tongariro National Park on the night of the event. Road damage was not reported and an injured climber was the only direct victim of the event.	Downer Edi Works Infrastructure [3](observation on site)
Storm Events 2008 31st of July 2008	During late July 2008, a severe weather front arrived in New Zealand. Both north and south islands were affected by heavy rain, which created flooding and landslides. From the 28-30th July, four researchers monitored the event's development. On site observation at the consultant's office took place on the 31st July when the storms badly affected the South Island's state highway network. Major damage observed included flooding in both north and south of Christchurch and a major landslide south of the Kaikoura Peninsula on SH1.	Opus International Consultants [4](Christchurch office)
Matata Flood 16th -30th May 2005	The flooding was a small-medium sized emergency. The event was localized, mostly in the Matata township and its nearby coastal area, which comprises the SH 2 Straight (approximately 5 km of road). As the emergency response was concentrated in very specific parts of the roading infrastructure, it involved organisations and their resources which were coordinated locally by the NZTA area engineer and Consultant.	NZTA engineer, Consultant and Contractor (observation on site)

The following subsections present the description and analysis of all observed exercises and events. For the sake of ease of understanding, throughout the report the domains under analysis were identified with initial capital letters, rather than in numerical terms for all the acronyms (e.g. the first success indicators for the physical domain were identified with F_{S1} rather than with F_{21}).

4.1 Marconi Exercise

The following subsections present the description of the exercise activities and the analysis of the Marconi Exercise.

4.1.1 Background and activities

On the morning of Friday 8th June 2007, the Auckland Region exercised coordination and communication between lifeline utilities and Civil Defence Emergency Management (CDEM) centres. The exercise focused on the response phase of a major emergency,

[3] Hereafter refereed as Works.
[4] Hereafter refereed as Opus.

simulated via a distributed tabletop exercise. The exercise was led by the Auckland Engineering Lifelines Group (AELG) representing Auckland transport, water, energy and telecommunication utilities in conjunction with the Auckland CDEM Group.

The Emergency Operation Centres (EOCs) at Auckland, North Shore, Waitakere and Manukau cities, the CDEM Group EOC team and the Lifeline Utility Coordinators took part in the exercise together with 24 lifeline utility organisations across all sectors. The transportation sector was represented by NZTA, On Track (the regional railways corporation), Air New Zealand and Auckland International Airport.

The aim of the exercise was to review and improve the lifeline utility coordination response processes. Specific objectives were:

- *i)* to review lifeline utility co-ordination processes in the Group EOC through escalating levels of emergency (culminating in a Group Declaration of a Civil Defence Emergency);
- *ii)* to assess the lifeline utility interface with the Group EOC with a focus on communication; and
- *iii)* information transfer.

Beyond these objectives, lifelines utilities were free to test their own plans, processes and procedures during the exercise.

Scenario

The scenario was an extreme weather event (tropical cyclone) causing significant damage and flooding in the Auckland Region. For the transport sector the damage scenario involved: a) high wind gusts (up to 170km/h); b) heavy rainfall; c) heavy sea swells and inundation; d) major flooding on the State Highways and on the main arterial routes. It also included a widespread and prolonged power outage with uncertain times for service restoration, possible shortage of fuels and telecommunications related impacts.

The seriousness of the scenario induced other effects such as main road closures, including the harbour bridge, traffic signal failures and subsequent gridlock, an increase of traffic accidents, inability of emergency services to reach relevant accident sites or hospitals, the need to evacuate people, and the need for telecommunications and electricity sector organisations to use transport routes to repair and maintain their infrastructures.

Roading utilities were assessed for their responsibilities such as liaison with the Police to control the roads; the use of contractors to assist with traffic control; restoration of priority routes, assisting Councils to manage evacuations, emergency services requirements, and arranging for aerial photography depending on the extent of damage.

Emergency Management Procedures Relevant for Marconi Exercise

Lifeline Utility Response & Recovery Protocols (AELG 2006) outlined recommendations for communication and information transfer between the lifeline utilities and the Emergency Operations CentreGroup (referred in the following as Group EOC). Figure 4.1 shows the expected relationship between lifeline utilities and the Group EOC according to the protocol for local emergencies (Figure 4.1a) and regional emergencies (Figure 4.1b). Utilities are expected to communicate directly with each localEmergency Operations CentreEOC (referred in the following as Local EOC) in the event of local emergency (Figure 4.1a).

In the event of a regional scale emergency, coordination of the lifeline utilities will occur at a regional level via a Lifeline Utility Coordinator, part of the Group EOC (Figure 4.1b). This was demonstrated during the Marconi Exercise when Local Authorities continued to report locally with relevant local EOCs (Figure 4.1b). The CDEM Group Public Information Management controls media and public communication during regional events. NZTA makes use of its "NZTA Emergency Procedures Manual: Region 2" (TNZ 2000) and the results of the Auckland Engineering Lifeline Group Project 5 (AELG 2004, AELG 2005), which identify priority routes for response and recovery activities in the Auckland region.

Activities at NZTA

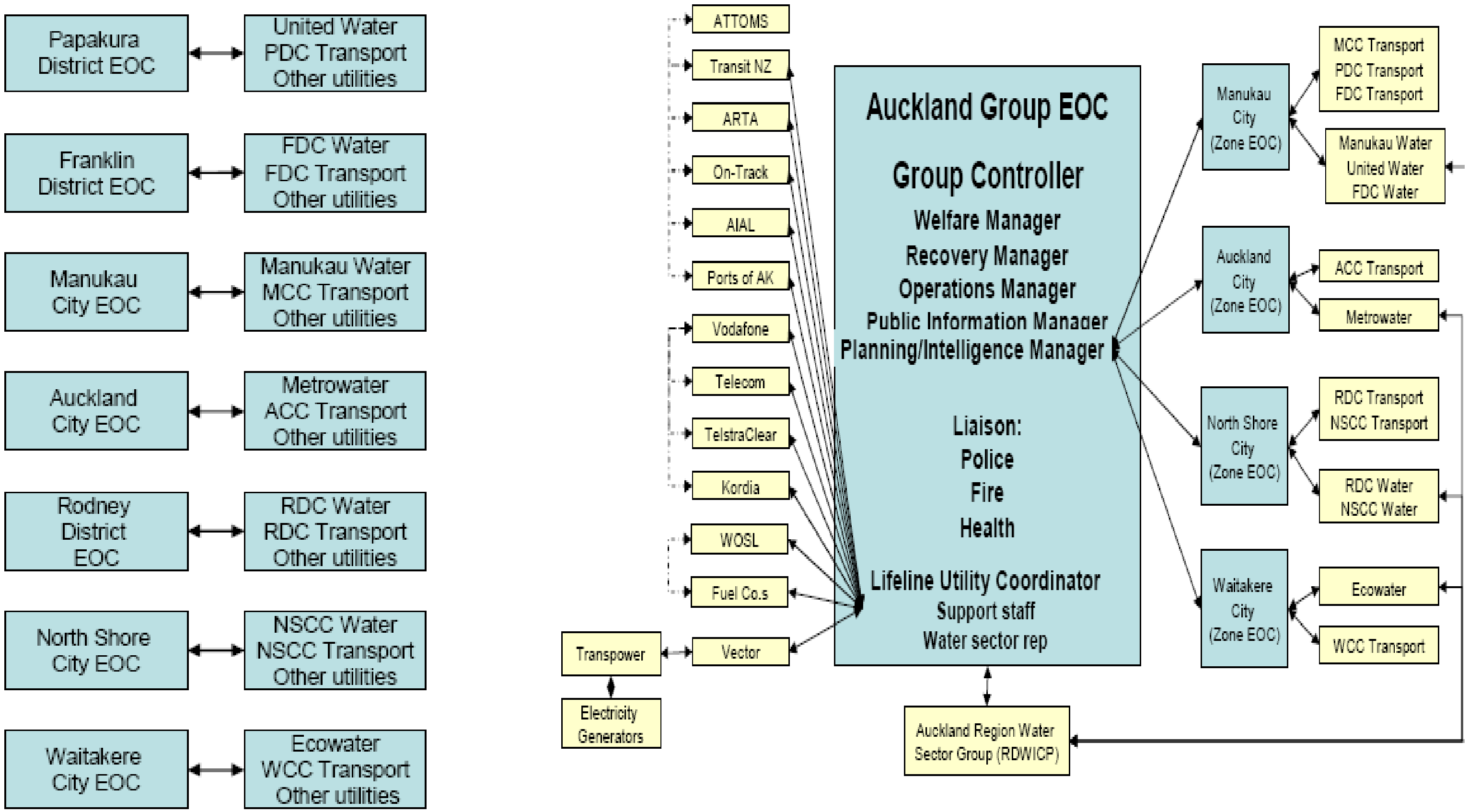
NZTA used the emergency management room in the Northcote Traffic Management Centre (ATTOMS Centre). The Centre is also used to monitor traffic 24 hours and 7 days a week in the Auckland Metropolitan area. Three participants from NZTA took part in the exercise plus the manager of the ATTOMS centre.

The exercise had a "warm start" in which it was assumed that the initial notifications and activation of EOCs had already been carried out after the issuing of a MetService weather forecast. This meant that staff were on standby and the EOC group was already activated. Exercise injects were sent via e-mail and as Word Documentattached files from the Lifelines Utility Coordinator to all the lifelines utilities taking part in the exercise. The injects comprised weather warnings and updates on the development or progress of the scenario. Three types of injects were received before the formal start of the exercise: 1) the weather warnings; 2) radio station news; and 3) the Auckland Group EOC Initial General Situation Report.

After the "warm start", NZTA focused on *impact assessment/communication* and i*dentification of pending issues and reporting back needs/ implications.* The following sub-sections describe the outcomes of these activities.

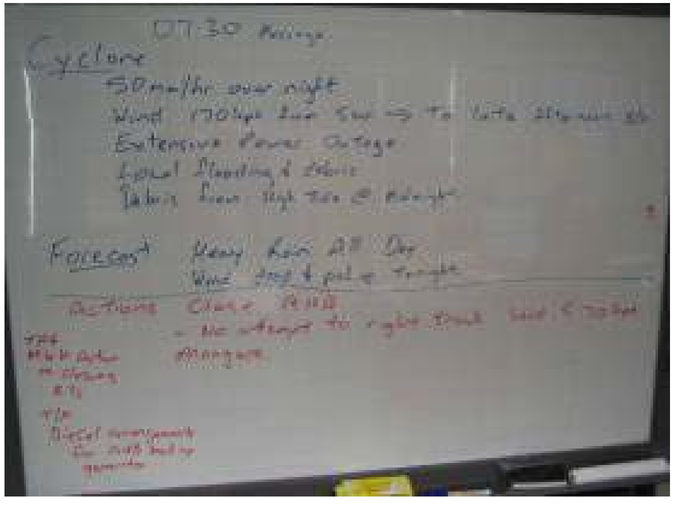
NZTA Impact assessment and communication

As NZTA road maintenance contractors did not participate in the exercise, the impact assessment was made exclusively on the basis of injects that were received from the Lifelines Utility Coordinators. In order to facilitate discussions about possible consequences to network operations and possible actions to be undertaken, key information was summarised on a white board (Figure 4.2b). The damage and disruption highlighted in the first three injects were summarised by NZTA staff on a laminated map, using blue colours, while the possible actions to be undertaken were highlighted with red colours (Figure 4.2a).



(a) (b)

Figure 4.1 - Communication and information transfer between Lifeline Utilities and EOCs or Group EOC after the Utility Response & Recovery Protocols (AELG 2006): a) Local Emergency, b) Regional Emergency.



(a) (b)

Figure 4.2 - Information from the event warning on: a) the Auckland Region laminated map; b) white board.

Subsequently NZTA, together with other lifelines utilities, were requested to state their current situation and report to the Lifeline Utility Coordinator. NZTA personnel produced a report comprising:

1) Overview of the scale and extent of event and the impact on the networks;
2) Major disruptions experienced including location and number of customers affected in each location and estimated restoration times;
3) Priority areas of response and actions;
4) Public information and precautions to be promulgated;
5) Requests for support or specific information;
6) Any other critical pending issues; and
7) Action required by Group EOC.

Identification of pending issues arising from the scenario and reporting back needs and implications

Following an external request from the Lifeline Utility Coordinator, NZTA had to analyse interdependencies among lifelines utilities, considering a detailed report from the electricity sector. This intended to encourage organisations to analyse pending issues arising from an electricity shortage. Furthermore, each lifeline utility sent a report to all other participants to share information. NZTA did not take action to summarise the information received from the other lifelines utilities.

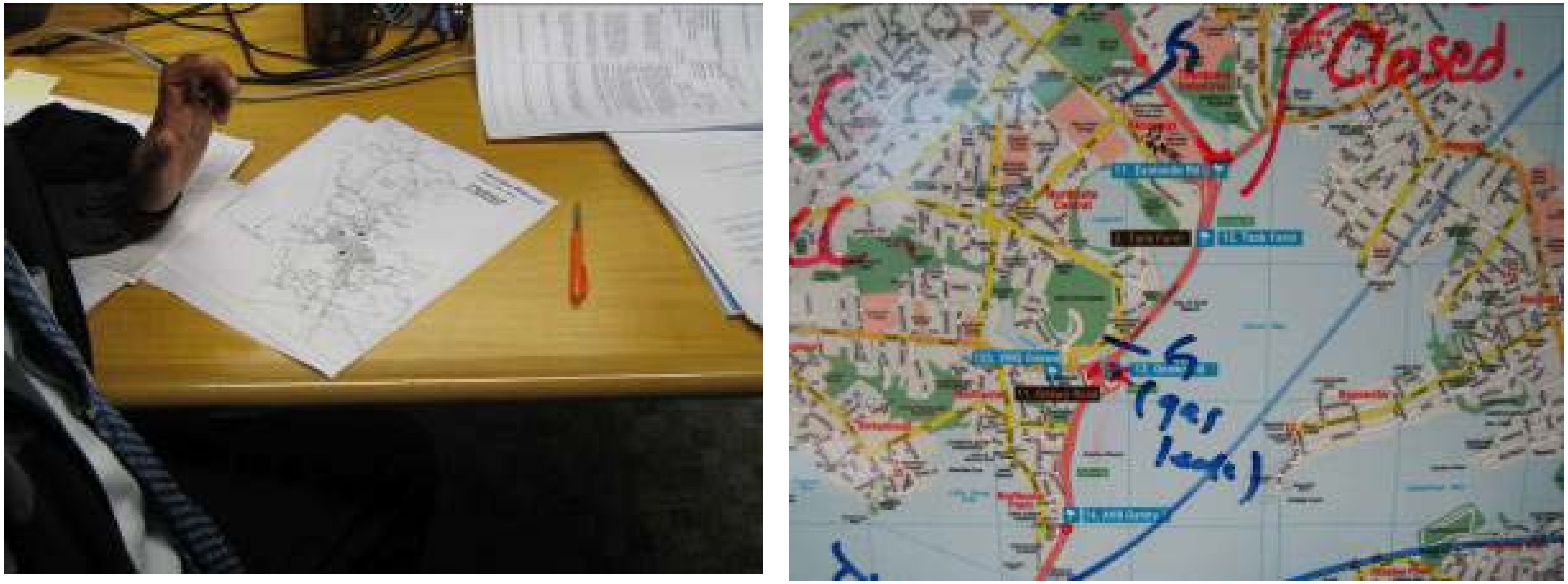
Regarding the electricity sector report, the lifelines utilities were required to deal with three other important issues, namely:

1) test of alternative communications;
2) identification of the services dependent on fuel and fuel stocks assured for the next 3-5 days (contacting the fuel supplier directly to ascertain this, if necessary);
3) use of the priority sites lists and maps provided in AELG (2005) as priorities for restoration.

Regarding the test of alternative communication, contacts via radio were attempted with the NZTA regional office in Auckland and with one contractor (Figure 4.3a). The initial attempt was unsuccessful. Communications via fax were also tested. The main road closures resulting after the damage scenario were sketched on a map showing that the highway network in the Auckland region (Figure 4.3b).

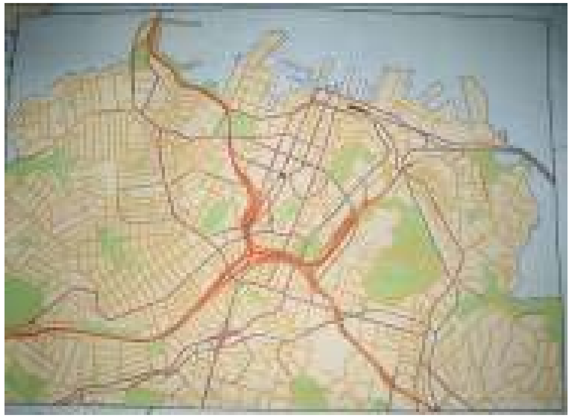
Fuel issues were discussed and NZTA stated that “contractors will need diesel on 10th June”. The fuel stocks assured for the next 3-5 days were identified on the map (Figure 4.5), but fuel suppliers were not contacted in order to confirm that information.

Finally, priority sites lists and maps were assumed to be the same previously identified by Auckland Lifeline Organisations Group (AELG 2004, AELG 2005). Figure 4.4 shows the map with priority routes for Auckland City that was displayed in the emergency management room (Figure 4.4a). Some relevant particulars from the same map are shown in Figure 4.4b and 4.4c (Auckland city centre and legend, respectively). NZTA reported back to the Lifeline Utility Coordinator after discussing the previous mentioned issues and by modifying and updating the first version of the report.



(a) (b)

Figure 4.3 - Pending issues arising from the scenario: a) test of alternative communications; b) collocation of fuel stocks on the map.



(b)

(a) (c)

Figure 4.4 - Auckland Lifelines Project 2006 (AELG 2006): a) Map of priority routes and location of strategic services; b) priority routes in Auckland city-centre; c) legend of the map.

4.1.2 QDM analysis

Given that the exercise's primary objective was "to review and improve the lifeline utility coordination response processes", involved organisations were not assessed on their own response processes. Attention was given to how their decisions were exchanged amongst lifelines and how "clear" they were. NZTA used the exercise in order to check information flow and communication protocols with other lifelines utilities. NZTA personnel undertook decision making discussions mostly about "how to communicate" during the event. Efforts were not observed to test NZTA's plans and procedures for implementing actions, nor did they specifically address the interdependencies or relationships with other lifeline organisations.Therefore, the analysis of the decision making process, QDM analysis, has been limited to the examination of the Information Domain (refer to section 2 for a comprehensive theoretical description).

Analysis of the Information Domain during Marconi Exercise

During the exercise, the NZTA team was interested in the best way of communicating and alternative ways of communicating in the event of a power shortage. Questions were raised about power availability and consequences on communication (internet, radios, mobile phones, etc.), possible internet/e-mail overload and the operability of web-cameras (CCVT cameras) and Variable Message Signs (VMS). Issues observed during the exercise are qualitatively described in the vulnerability matrix shown in table 4.4.The results of the QDM analysis for the information domain are summarised and represented in Table 4.5. It is worth noting that the data processing observed during Marconi Exercise was analysed as part of the Information Domain. All the sub-tasks related to the data processing were jointly analysed and summarised under a unique acronym, namely DATA, both in the Vulnerability (Table 4.4) and in the Assessment Matrix (Table 4.5).

Communication with the public and the media was identified as a high level of importance. The NZTA team were aware of, and discussed, the necessity of coordinating media releases ("…*we have to be careful about the conflict information with media information…*") and of coordinating communication at both local and regional levels. Overall, communications with the media and the public were performed at a high level of commitment and accuracy, although there was a reluctance to release information. By the end of the exercise the NZTA team was successful in achieving a "good" level of *information connectivity* at the intra-organisational level and with the public. At the intra-organisational level the *information richness* was judged as "limited", since the information sharing was limited to a verbal discussion. The *information reach* was affected by a few tangible vulnerabilities and was judged as"poor" (Table 4.4).

Regarding the communication with the media/public, a "fair" level of *information richness* was achieved using multiple forms of tools to share information (e.g. media release and dedicated websites), while *information reach* was affected by a few vulnerabilities (Tale 4.4) and was performed at a "limited" level.

The inter-organisational communications (communication with other lifelines utilities) was performed according to the Lifeline Utility Response and Recovery Protocols that required liaising with the Lifeline Utility Coordinator. However, the NZTA team did not rely on the coordination of communication by the Lifeline Utility Coordinator. The NZTA team expressed a wish to have someone from NZTA representing them at the Group EOC. The *level of connectivity* reached in the inter-organisational communications has been judged as “poor”.

The *information richness* at the Group EOC (inter-organisational level) was judged as “fair”, because both multimedia and audio tools were used to share information. The *information reach* provided regular, simultaneous and selective communication, but it was also affected by different vulnerabilities (Table 4.4), therefore it was judged “limited”. It is worth remebering that, *the intra-organisation communication* was limited to the level of verbal discussions amongst NZTA personnel, because consultants and contractors were not involved in the exercise.

Overall analysis

The degree of fulfilment of the success indicators pertinent to the Information Domain resulted in $F_{I1}=3$, $F_{I2}=2.25$, $F_{I3}=1.75$, respectively for Connectivity (S_{I1}) Information Richness (S_{I2})and Information Reach (S_{I3}). Assuming the same proportion relevance $\beta_i=0.33$ for all of the success indicators and applying Equation 3.2, the performance of the Information Domain within the decision making process is judged as “fair” corresponding to ($D_I=2.33$).

Considering that the Information Domain was the only one observed during Marconi Exercise, the global score for the decision making process results $DM=D_I=2.33$. According to the assumed qualitative scale (Table 4.3), $DM=2.3$ means that the organisation’s performance result is “Fair Resilience” (adequate but some areas of dysfunction with limited adaptability; not effective in all circumstances; limited in solutions delivery; some feedback to involved organisations).

Table 4–4 - Information Domain Vulnerability Matrix after Marconi Exercise.

INFORMATIONDOMAIN

S_{I2}- Information richness

INTRA	INTER	MEDIA PUBLIC	DATA	*Tangible Vulnerabilities*	*Intangible Vulnerabilities*
-	-	-	☑	Use of non-codified abbreviations and symbols	-
-	-	-	☑	Use of the same situation report for the whole exercise, difficulties in identifying changes in the situation	-

S_{I3}- Information reach

INTRA	INTER	MEDIA PUBLIC	DATA	*Tangible Vulnerabilities*	*Intangible Vulnerabilities*
-	☑	☑	-	Potential difficulties of accessing the information released due to power outage	-
-	-	☑	-	Lack of TV and radio in the emergency room. Lack of awareness of the information that media were realising to the public	-
-	☑	-	-	Lack of a dedicated terminal for each one of the decision makers for accessing information	-
-	☑	-	-	Communication was not always timely	-
☑	-	-	-	Communication not always far-reaching, some of the contractors were not receiving NZTA email	-
☑	-	-	-	Radio connection with consultants was not always working	-
-	-	-	☑	Information summary and report on the laminated map and board was insufficient and too inaccurate to allow for a clear representation of the evolving scenario	-

Table 4–5 - Information Domain Assessment Matrix after Marconi Exercise.

	INFORMATION DOMAIN	**Applicable**	**Performance Level**				**Degree of Fulfilment**
/SUCCESS INDICATORS	*S_{I1})Connectivity*	☑	4	1	4	N/A	**3**
	S_{I2}) Information richness	☑	2	3	3	1	**2.25**
	S_{I3}) Information reach	☑	1	2	2	2	**1.75**
			INTRA	**INTER**	**MEDIA/ PUBLIC**	**DATA**	**D_I**
			SUB-TASKS				**2.33**

Applicable: Yes ☑, No ☐

Level of Performance 5 Excellent 4 Good 3 Fair 2 Limited 1 Poor

4.2 Icarus Exercise

The following subsections present a description of the exercise activities and analysis of the Icarus Exercise.

4.2.1 Background and activities

On the morning of 22nd November 2007, the NZTA Wellington Regional Office, in conjunction with its consultants and contractors, exercised its emergency response arrangements. The exercise was part of the scheduled annual training organised by the NZTA Wellington Regional Office and involved two consultancy companies (MWH and OPUS), one contractor (Fulton Hogan) and the Greater Wellington Regional Council (GWRC).

One of the aims of the exercise was to train staff in their respective roles. The exercise was also used to test the practicality of the aerial reconnaissance arrangements that have been developed through a Memorandum of Understanding (MoU) between NZTA and Greater Wellington Regional Council.

This report presents in detail, the observation conducted at the Fulton Hogan Emergency Operations Centre (EOC). Furthermore, observations of the NZTA and Lifeline Coordinator responses are discussed. Finally, findings and conclusions are presented regarding decision making and communication issues identified after experiencing the Exercise Icarus.

Scenario

The scenario was based on the Capital Quake Exercise in 2006, which comprised a major rupture in Wellington's fault, (see Appendix A for scenario's details). The NZTA made a few modifications to the scenario to meet the specific objectives of the exercise. These modifications focused on preparedness and decision making related to reopening State Highway (SH) 1 north of Wellington (Exercise Icarus Planning Document, 2007). The specific exercise objectives were:

- Practice EOC operations and role delegation;
- interpret reconnaissance information acquired by FH field staff and aerial photographs; and
- train and practice interactions between organisations and the Lifeline Utility Coordinator.

A research team member took part as an observer at Fulton Hogan's EOC. The aim was to observe how decision making and communication is performed in a real event simulation.

The exercise ran from 9.00 am to 12.30 pm and included the various small events as shown in Figure 4.5. A description of each small event is listed below:

1. Bridge over motorway at Johnsonville – holes in the road on both sides of the bridge – soil collapsing;
2. Rail bridge over motorway at bottom of Ngauranga Gorge – smoke coming out of tunnels, East (South) bound lanes blocked;
3. Aotea Quay bridge onto Hutt Road – span fallen down with obvious displacement of bridge both ways;
4. Motorway over rail yards – one span on catchers and displacement to both north and south bound lanes;

5. Motorway off-ramp by James Cook hotel blocked with debris by a fallen building;
6. North end of Terrace Tunnel – slips cover north bound lane;
7. Portal at eastern end of Mt Vic Tunnel - blocked by a landslide;
8. Southbound section of road between Pukerua Bay and Plimmerton - slips; and
9. Between Pukerua Bay and Fisherman's Table – massive slips/blockages (and a passenger train half visible within one of the slips).

Even though the exercise's primary goal was the reopening of SH 1, conflicting information about SH58 was given in order to create a more complex decision making problem for participants. Furthermore, it was expected that organisations could improvise and create injects in order to test their own procedures and to train their respective emergency response teams.

Damage and information about the road network was provided to participants through a series of injects. Annex A-1 presents the scenario scene setter and the timetable details for the respective injects. These include extra injects, which were used depending on the organisations' response actions.

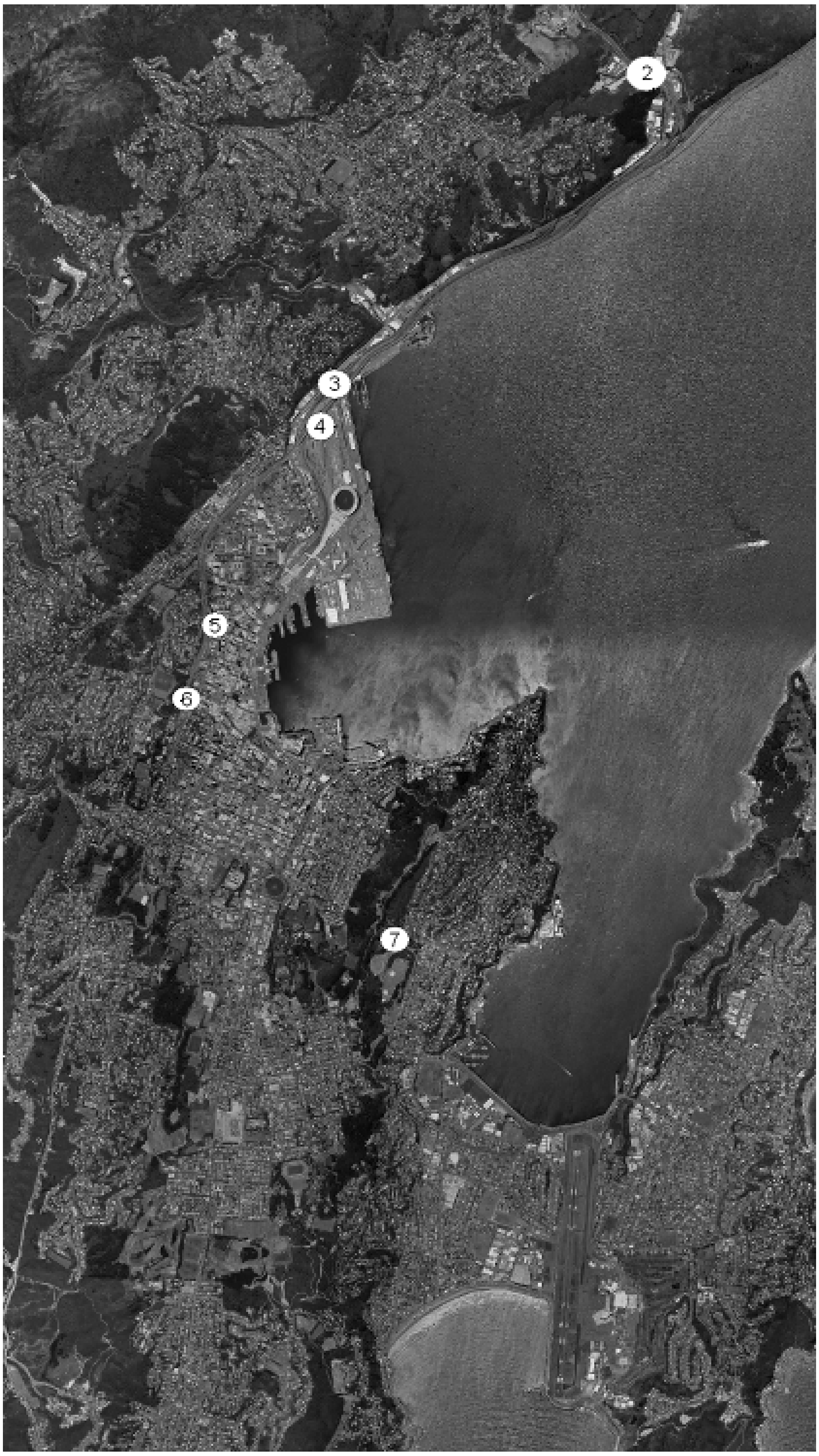


Figure 4.5 - Snapshot of Damage in the Road Network.
(Source: Aerial photograph from Land Information New Zealand, 2007)
Note: Damage 1, 8 and 9 are located outside of the aerial photograph above.

Activities at the Fulton Hogan Emergency Operations Centre

The exercise was observed at Fulton Hogan Emergency Operations Centre (EOC) which was set up at the Fulton Hogan Wellington area office (Marine Parade, Petone). The exercise observation can be divided into three different phases: 1) Pre Exercise, 2) Exercise Observation and 3) Post Exercise. The description of each phase is presented below:

> <u>1) Pre Exercise:</u> The room was initially arranged to reflect possible effects from an Earthquake (Figure 4.6). This was followed by a quick introduction presenting the scenario, exercise rules, objectives, etc. Fulton Hogan's manager clarified his role during the exercise and the expectations of FH's team in terms of response and emergency management.

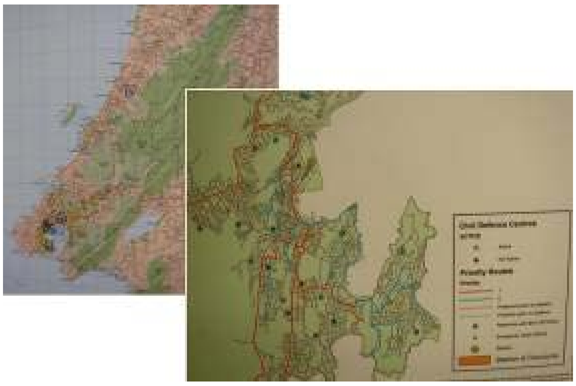
Figure 4.6 - EOC's arrangement before 9.00 am (Exercise Start).

The team discussed available resources at this stage (e.g. building facilities, communication infrastructure) so that the exercise would flow more smoothly. The following were made available for FH personnel during the exercise:

- A single room commonly used for meetings in the company;
- A Radio Transmitter (RT) to communicate with other organisations (Figure 4.7a);
- A single landline phone;
- 2 white boards fixed onto the walls;
- A desktop computer;

- A box containing an emergency kit including safe vests, gloves, buckets, non perishable food, torches, gas torches, blankets, respirators etc (Figure 4.7b);
- 5 tables and a carrel;
- A flip chart;
- A portable white board;
- Maps for the Wellington Area including a map with state highways, urban areas etc. and a map from Civil Defence (CD) showing priority routes and CD Centres (Figure 4.7c);
- Emergency response forms;
- A box containing office consumables (Figure 4.7d);

a - Radio Transmitter.



c - Maps Used During the Exercise.

b - Fulton Hogan's Emergency Box.

d - Office Consumables.

Figure 4.7 - Some of the Available Materials for FH's Personnel.

2) Exercise Observation: The participants had to arrange the EOC room after the formal start of the exercise at 9.00 am. Figure 4.8 shows the EOC room arranged by FH Team. In addition to taking notes about actions and discussions, pictures were taken, notes registered, discussions recorded and a survey form completed as part of the observation of the exercise. The data collected comprises 45 pictures, a three page long survey and approximately 36 minutes of audio recordings. This sub-section uses a timeline to present injects, decision making, communication and discussions on the morning of the exercise; this is shown in Table 4.7. Annex A shows figures referred to in this table.

While every effort was made to capture all available data in this table, it is inevitable that some actions, decisions or discussions may have been missed due to the complex and extremely dynamic nature of emergency exercises. The observation focused on general aspects of decision making and communication performed during emergency events and how they could be improved.

Figure 4.8 - EOC Arranged After the Exercise Started.

<u>3) Post Exercise:</u> A hot debrief was conducted immediately after the exercise was officially finished. Participants were asked to complete a survey form (Annex B). The team then discussed the strengths and weaknesses that were observed during the exercise. The following issues were identified during the hot debrief:

- Stress management (especially when injured staff are involved);
- Emergency Depot Roles clarification (EOC Manager, Information and Communication Manager, Road Clearing Operations Manager and Logistics and Staff Requirements Manager);
- Information sharing and support from other organisations;
- The use of NZTA Emergency Response Plan, Fulton Hogan's procedures and Role Description laminated sheets;
- EOC Room layout;
- EOC equipment (e.g. desks, desktop computer, printer, RT);
- EOC location at Fulton Hogan area office at Marine Parade, Petone, Wellington;
- Power availability during real events and generators; and
- Emergency box items.

4.2.2 QDM analysis

Given that the exercise's primary objective was "…*to train staff in their respective roles… and to test the practicality of the aerial reconnaissance arrangements…*", it was necessary to consider the SHO in terms of physical, information, cognitive, social domains.

Analysis of the Physical Domain

Exercise Icarus was conceived and run as an extended functional exercise, including features typical of a full scale exercise. These included the simulation on the field of resources deployment and damage assessment operations.A few vulnerabilities affecting these operations were observed and reported in Table 4.6. However, with simulations it is considered inappropriate to judge the performance of the task and subtasks identified in the physical domain as they are not in reality conducted. Hence, the assessment matrix for the physical domain was not completed.

Table 4.6 - Physical Domain Vulnerability Matrix.

PHYSICAL DOMAIN					
S_{P1}- *Minimisation of road closures duration and variability*					
Task/Sub-tasks				***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
DHR	**DPR**	**TTM**	**DAM**		
☑	☑	-	-	-	Office staff had problems identifying the location of field crews and what they were doing as well as identifying local physical resources
☑		-	-	Staff shifts not implemented	-

Analysis of the Information Domain

The intra-organisation communications analysis refers to communications between FH decision makers and FH personnel in the field. Inter-organisation communication was established with NZTA Regional Office and Opus consultants that joined NZTA EOC and with the Greater Wellington Regional Council that was also involved throughout the exercise. Communications with media and public were not performed.

Table 4.7 summarises the outcomes relating to both tangible and intangible vulnerabilities, and the degree of fulfilment of the success indicators in the information domain for the decision making processes observed during the Icarus Exercise.

During the exercise, a lot of information was acquired in a short amount of time. Within the first hour of the exercise (from 9.00 to 10.00 am), information about observed damage and conditions, and about the deployment of physical and human resources, were collected and exchanged between organisations. This reached the decision makers in Fulton Hogan via field personnel, and between Fulton Hogan EOC and NZTA EOC.

The quality of the interactions between the decision makers was affected by information sharing, which was not always accurate at intra or inter organisational levels. This is the most critical issue that has contributed to the assessment of this domain. The *information and dataconnectivity* between the various decision makers was assessed as "limited" both at inter and intra organisation levels.

Notwithstanding the variety of tools used to share information, there was a lack of adequate knowledge about how to properly manage and process the information acquired. The methods used to record and update information were also observed. As a result the *information and data richness* was judged to be at a "limited" performance level. Finally, *information reach* was assessed as "fair" at inter-organisational level, despite the observation of a few tangible and intangible vulnerabilities. It is worth noting that it has not been possible to assess the information reach at intra-organisation level.

Table 4.7 - Information Domain Vulnerability Matrix.

INFORMATIONDOMAIN					
S_{I1}- Level of Connectivity					
Task/Sub-tasks				***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
INTRA	**INTER**	**MEDIA**	**PUBLIC**		
☑	☑	N/A	N/A	Information about available resources was not well shared between FH office and field personnel and between FH and NZTA	-
S_{I2}- Information richness					
INTRA	**INTER**	**MEDIA**	**PUBLIC**	***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
N/A	☑	N/A	N/A	FH existing form for collecting data inadequate	Lack of adequate knowledge of how to properly manage and process the information acquired
N/A	☑	N/A	N/A	Lack of an organised method to record and update information (e.g. GIS mapping)	-
S_{I3}- Information reach					
INTRA	**INTER**	**MEDIA**	**PUBLIC**	***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
N/A	☑	N/A	N/A	Only one person dedicated to answer the calls, a few missed calls	Impossible to restrict of share information based on roles (lack of information selectivity

Summarising, the success indicators pertinent to the Information Domain, namely (S_{I1})Connectivity, (S_{I2})Information Richness and (S_{I3}) Information Reach, achieved $F_{I1}=2$, $F_{I2}=2$, $F_{I3}=3$, respectively. Assuming the same proportion relevance $\alpha_i=0.33$ for all of the success indicators in the Information Domain, the performance of the Information Domain and applying Equation 3.2, the performance level is "fair", (D_I=2.33).

Table 4.8 - Information Domain Assessment Matrix.

INFORMATION DOMAIN		**Applicable**	**Performance Level**				**Degree of Fulfilment**
SUCCESS INDICATORS	*S_{I1}) Connectivity*	☑	2	2	N/A	2	2
	S_{I2}) Information richness	☑	N/A	2	N/A	2	2
	S_{I3}) Information reach	☑	N/A	3	N/A	3	3
			INTRA	**INTER**	**PUBLIC**	**DATA**	**D_I**
			SUB-TASKS				**2.33**

Applicable: Yes ☑, No ☐

Analysis of the Cognitive Domain

In general, a good level of situation awareness was observed among the participants, as well as a good level of training and experience. The decision makers were observed acting on the basis or their common sense and their experience. There was very limited evidence of a response manual, emergency response forms (e.g. Operational Action Plan Update, Message Log, Action Log, Staff Availability, Roles' description sheets etc) being used at all.

During the exercise, individual skills were seldom used to their full capability, especially during the first half of the exercise. The staff were not fully aware of their role and duties during the exercise and that contributed to a stressful situation and affected the unit's cohesion. However, thanks to good leadership, the decision making team was re-structured in the second half of the exercise (i.e. re-allocation of participants in suitable roles considering their particular skills). This change contributed to a better team performance in collecting, recording, sharing and communicating information with other organisations, deploying available physical and human resources, and making decisions. The ability to learn from an initial mistake is interpreted as a positive factor of resilient decision making (e.g. decision making showing a learning attitude).

Considering the tangible and intangible vulnerabilities identified in Table 4.9, an assessment matrix was compiled (Table 4.10). It is worth noting that an expert judgment has been expressed on the degree of fulfilment of the different success indicators without the need to express a judgment about the performance level achieved for the different cognitive elements identified in this domain. These include scenario perception, understanding of needs, and future projection.

Pertinent success indicators (S_{C1} Individual Situation Awareness, S_{C2} Level of Training and Experience and S_{C3} Intangibles of Leadership and Unit Cohesion) reached $F_{C1}=3$, $F_{C2}=3$, $F_{C3}=4$, respectively. Assuming the same proportion relevance $\alpha_i=0.33$ for all of the success indicators, a "good" performance was reached in the Cognitive Domain, i.e. D_C=3.33.

Table 4.9 - Cognitive Domain Vulnerability Matrix.

COGNITIVE DOMAIN				
S_{C1}- individual situation awareness				
Cognitive Elements			***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
Scenario Perception	**Understanding of Needs**	**Future Projection**		
N/A	☑	☑	-	Staff were not fully aware of their role and duties
S_{C2}- level of training and experience				
Cognitive Elements			***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
Scenario Perception	**Understanding of needs**	**Future Projection**		
N/A	☑	☑	-	Individuals skills were seldom used to their full capability
☑	☑	☑	Absence of decision making support tools for enhancing the knowledge management	
S_{C3}- intangibles of leadership and unit cohesion				
Cognitive Elements			***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
Scenario Perception	**Understanding of needs**	**Future Projection**		
N/A	☑	☑	-	Participants were not associated to suitable roles considering their particular skills

Table 4.10 - Cognitive Domain Assessment Matrix.

	COGNITIVE DOMAIN	**Applicability**	**Degree of Fulfilment**
SUCCESS INDICATORS	*S_{C1}) individual situation awareness*	☑	3
	S_{C2}) level of training and experience	☑	3
	S_{C3}) intangibles of leadership and unit cohesion	☑	4
			D_C
			3.33

Applicable: Yes ☑, No ☐

Analysis of the Social Domain

The exercise was part of NZTA annual training and did not include the participation of the emergency management agencies(e.g. local/region Civil Defence EOC). Given this, the quality of decision making processes in the social domain was assessed only taking into consideration coordination of actions with participating agencies.

Table 4.11 summarises the main issues identified through participants' feedback as part of the post-exercise debrief. It highlights the need for a well established working process among organisations. During the post-exercise debrief it was emphasised that priorities must be defined by the NZTA. The consultants and contractors were required to be ready to organise the responses according to the priorities defined.

Table 4.11 - Social Domain Vulnerability Matrix.

SOCIAL DOMAIN			
S_{S3} -coordination of actions with all involved agencies.			
Cognitive Elements		***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
INTRA	**INTER**		
☑		-	A well established coordination of action with all involved organisations has yet to be developed

Accounting for the observed vulnerability, the degree of fulfilment of the success indicators S_{S3} *Coordination of Actions with all Involved Agencies* was evaluated as "limited" (S_{S3}=2). Being the only success indicator applicable to the case of Icarus Exercise, the performance for the Social Domain was assessed to be "limited" D_S=2 (Table 4.12).

Table 4.12 Social Domain Assessment Matrix.

SOCIAL DOMAIN		**Applicability**	**Degree of Fulfilment**
SUCCESS INDICATORS	*S_{S1}) responsiveness to the needs of emergency management agencies*	☐	N/A
	S_{S2}) technical advice to leading emergency management agencies and lifeline groups	☐	N/A
	S_{S3}) coordination of actions with all involved agencies	☑	2
			D_S
			2

Applicable: Yes ☑, No ☐

Overall analysis

Considering the domain scores and assuming the same proportion relevance γ_d *=0.25* for all domains, the performance is calculated as *DM*=2.55 which means that the resilience of the decision making process is classified as "Fair" (adequate but some areas of dysfunction with limited adaptability; not effective in all circumstances; limited in solutions delivery; some feedback to involved organisations).

4.3 Capital Quake: Ruaumoko Exercise 2006

The following subsections present the description of exercise activities and the analysis of the Capital Quake Exercise.

4.3.1 Background and activities

On the 14-15th November 2006 a national civil defence exercise was held to test arrangements for managing a major earthquake on the Wellington fault. This exercise tested central and regional civil defence emergency plans. It was also an opportunity for key organisations to practice their response arrangements.

Roading organisations that agreed to participate in the exercise included Fulton Hogan, NZTA Wellington regional office, MWH, OPUS, and Wellington City Council (WCC) roading division. The objectives of the exercise for these organisations were to:

1) Test disaster response arrangementsand identify how these disaster response plans can be improved;
2) build skills and capacitywithin these organisations to ensure that staff are aware of their roles and responsibilities and build up the number and skills of staff available to respond;
3) to engage staff in the importance of planning for major crisis events; and
4) to buildteams across organisations that are able to work effectively together in times of crisis.

A specific objective for NZTA was to test the interfaces between the NZTA regional office, NZTA national office and the Ministry of Transport led Transport Cluster.

Scenario

The exercise assumed that an earthquake took place at 5:30am on the morning of the 14th November and role played the first two days following the earthquake. Damage and information about the road network was provided to participants through a series of injects. Annex C presents the scenario scene setter and the timetable details with the respective injects. These include extra injects, which were used depending on the organisations' response actions.

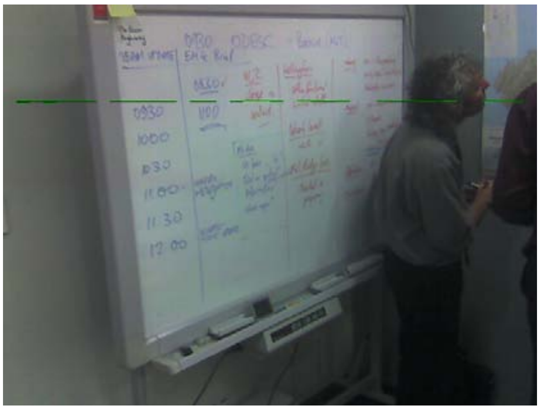
State Highway Overview

The NZTA national office was activated early on day 1 (based in Wellington, but in a real event this would be run from Auckland). Figures 4.9a and 4.9b show the initial activities at the NZTA Emergency Operation Centre (EOC) room. Upon its activation, NZTA personnel worked on a backlog of information about the event. It took 40 minutes to process available information. Figures 4.10a, 4.10b, 4.10c and 4.10d show the recording and processing activities conducted in the EOC room.

(a) Discussions at the NZTA national office EOC room

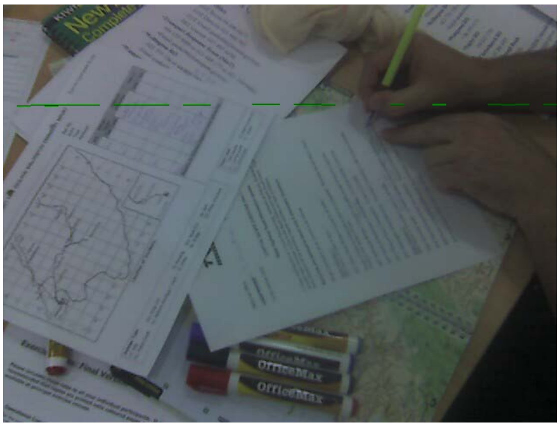
(b) Personnel at NZTA national office EOC room

Figure 4.9 - NZTA National office activation.

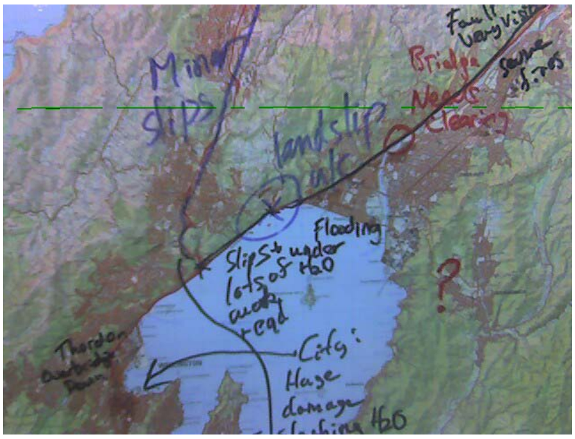


(a) White board with the summary of events and actions

(b) Recording of latest info on events



(c) Forms used in the response



(d) Graphical representation of the available resources and actions

Figure 4.10 - Recording and processing activities at the NZTA National office.

The first priority for the NZTA National office was to activate resources from outside of the region and to start with regional reconnaissance. Early in the morning of Day 1, there was little communication with the NZTA regional office in Wellington due to failures in communications. Late morning on Day 1 some information started filtering through from NZTA Regional office into NZTA National office. This included injects such as damage observations and some high level information about what contractor resources are where. Due to limited information availability about the road closures in the Wellington region, NZTA National office personnel decided to allocate resources to re-open State Highway around Petone and Lower Hutt. It was concluded that State Highway 2 would be a “no go” area due the significant impact of the earthquake fault.

On Day 1, the NZTA Regional Office were yet to set up a formal EOC so it was NZTA National office that had a greater understanding of the overall situation.

During the morning of Day 2, more local level awareness of the situation began to form. The NZTA Regional EOC was established (starting from 7:30am) and communications between the Regional and National EOC’s became more regular. As a result better quality information started to flow from mid morning. The NZTA Regional office was actively exercising their team from 7:30 am to 12:30 pm.

This allowed for information sharing and collaboration between NZTA national and regional offices. During these interactions, a few issues were observed; they include:

- Even though satellite phones were available at the national office, there was no way to use them because the regional office did not have similar devices;
- there were doubts and questions around who to address the reports to at the NZTA regional office;
- different offices required different levels of information. For example, maps produced at the National office were strategic and showed limited details of the network, whereas regional office's maps were very comprehensive and very detailed; and
- no formal risk assessment was performed to reach the conclusion of that resources should be allocated to State Highway 1.

4.3.2 QDM analysis

Given the exercise's objective of testing all functionalities and interactions between NZTA offices, it was possible to consider involved SHOs in terms of physical, information, cognitive, social domains.

Analysis of the Physical Domain during the Capital Quake Exercise

The EOC was promptly set up within 15 minutes of the commencement of the Capital Quake exercise. This fulfilled Disaster Response Plan (DRP) requirements and roles and responsibilities were assigned between the most senior staff members present. An initial briefing on the earthquake which set the stage for the operational response and setting priorities was also conducted.

However, as the exercise progressed each participating organisation seemed to have its own set of priorities; this often resulted in conflicting actions. For example, NZTA New Zealand's Emergency Response Plan Document suggested the following priorities with regard to response actions: 1) the importance of the highway; 2) resources available, and 3) practicality of action. However, Fulton Hogan's Disaster Response Plan (DRP) states "*Re-opening priority access routes is the main priority unless Civil Defence Controller advises otherwise*". As a result staff and resources in Fulton Hogan were allocated to re-opening priority access routes as follows:

- Operational capability of the Wellington International Airport Corporation (WIAC). This was of utmost priority to enable emergency airlifts and delivery of relief personnel and supplies;
- road access (route) between the airport and the hospital to enable movement of the injured etc; and
- general road clearance along major arterial routes within the city.

Based on these priorities, Fulton Hogan tallied up available resources using whiteboards and maps and assigned a total of 3 road crews for reconnaissance, 2 road crews for general road clearance, 1 for the Airport, 1 for road clearance along Rongotai access route and 1 crew for food and fuel supplies. Shortfalls in resource requirements were noted and contacts established with other depots for assistance. Fulton Hogan activated a mutual aid agreement which was in place with the equipment hire organisation HireQuip. This meant that plant and equipment requisition was judged unnecessary. There were ongoing communications with field crew for updates, reaffirmation of road clearance focus and priorities, morale boosting and welfare concerns.

The lifelines CDEM group followed priorities according to the Wellington Region CDEM Group Plan document. CDEM priorities include preservation of life, government, maintenance of law and order, property protection and guarantee of essential services including transport services. Hence, re-establishing roading and runway access observed in the Capital Quake exercise was part of CDEM priorities.

Another issue identified with regards to priority setting, was the safety of staff. A particular example is that of Fulton Hogan's personnel that were trapped in the tunnel. A few participants expressed concern about how such an incident would be managed in a real event. The post-exercise debrief revealed that the safety of colleagues was among the top priorities for staff, but this was not clearly expressed either in the NZTA's Emergency Response Plan or in Fulton Hogan's Disaster Response Plan.

Table 4.13 summaries the tangible and intangible vulnerabilities observed during the Capital Quake Exercise for the Physical Domain. In particular vulnerabilities were identified considering the success indicator S_{P2}*- Maximisation of accessibility to strategic services and places*, which reflected the priorities agreed by all of the organisations involved.

Table 4.13 - Physical Domain Vulnerability Matrix.

PHYSICAL DOMAIN					
S_{P2}*- Maximisation of accessibility to strategic services and places*					
Task/Sub-tasks				***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
DHR	**DPR**	**TTM**	**DAM**		
☑	☑	-	-	-	Office staff had problems identifying where field crews were and what they were doing, and locating physical resources
☑	☑	-	-	Resource optimization options seemed to be very limited during the early stages of the response	-
☑		-	-	Staff shifts was not implemented	-
-	☑	-	-	Decision-makers were not certain of the range of available options	-

Considering these vulnerabilities, the deployment of physical and human resources during the Capital Quake (2006) exercise was operated at a "limited" level D_P=2 as shown in Table 4.14.

Table 4.14 - Physical Domain Assessment Matrix.

PHYSICAL DOMAIN		Applicability	Performance Level				Degree of Fulfilment
SUCCESS INDICATORS	*S_{P1}) Minimisation of road closures duration and variability*	☐	-	-	-	-	**N/A**
	S_{P2}) Maximisation accessibility to strategic services and places	☑	2	2	-	-	**2**
	S_{P3}) Minimisation response and recovery costs	☐	-	-	-	-	**N/A**
			DHR	**DPR**	**TTM**	**DAM**	**D_P**
Applicable: Yes ☑, No ☐			**SUB-TASKS**				**2**

Analysis of the Information Domain during the Capital Quake Exercise

Information sharing played a major role in the response operation of the Capital Quake Exercise. Participating organisations collected information using available resources in the EOC. The communication tools (satellite phone, cellular phones, landlines, emails, and radio transmitters) were the main resources used to collect information from other organisations. There was regular communication about resource availability with other contractor installations,' this included updates on work schedules and damage reports. Communication was maintained at 1-hour intervals through open-channel reports. However communication hitches were experienced with other agencies like the Wellington Emergency Management Office (WEMO). NZTA and WIAL (Wellington International Airport Ltd) had no satellite phone.

Some organisations assigned personnel to be in charge of each communication tool (e.g. NZTA National Office). Different results in the information and data handling and sharing were observed as a consequence of these different practices. Organisations that standardised information and data processing often achieved a higher level of consistency and efficiency. Inconsistent and unreliable information was obtained from those organisations that did not clearly assign their personnel with specific tasks.

Information about the location, damage, time and impact of the incidents was collected during the exercise. Nevertheless, available information was rarely used in all organisations. Instead, personnel's knowledge played a significant role in shaping the understanding of the situation on the site.

A general tendency of being reactive to incoming information was observed, as opposed to a more pro-active approach. However, pro-active information seeking was also identified in certain organisations. It occurred particularly when the information was needed to make a decision. One of the reasons causing the reactive approach was identified in NZTA Regional office, where the personnel were overwhelmed by the incoming information early in the second day of the exercise.

All organisations managed the collected data items using standard forms, plotted them on maps, and recorded incoming information in a log report. It has to be noted that one organisation (Fulton Hogan Petone) did not prepare maps for the emergency exercise.

Instead, hand-drawn maps were used to plot the situation, based on received information. Overall, adopted practices worked well in providing a big picture understanding of the emergency situation.

After receiving and processing data items and information, most participant organisations had the tendency to keep collected information for their own response operations. Limited efforts were observed to disseminate the compiled information to other organisations. The exception was NZTA National Office's effort to prepare regular media releases, as suggested in the NZTA Emergency Response Plan.

Table 4.15 summarises the tangible and intangible vulnerabilities observed during the Capital Quake Exercise for the Information Domain of the decision making process. In particular, vulnerabilities comprised success indicators S_{I3}- *Information reach*, while no particular vulnerabilities were highlighted for the other two success indicators of the Information Domain.

Table 4.15-Information Domain Vulnerability Matrix.

INFORMATIONDOMAIN					
S_{I3} - Information reach					
INTRA	**INTER**	**MEDIA**	**PUBLIC**	***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
☑	☑	-	-	Some organisations did not assign personnel to collect, share and process data and information	-
☑	-	-	-	-	Limited efforts were observed in disseminating the compiled information to other organisations
☑	-	-	-	-	Difficulties in transferring/ explaining actions and information from the NZTA National Office CDEM and operations rooms
-	-	☑	☑	Absence of agreed templates/rules	Very strong concerns in releasing information to media

The connectivity observed at inter and intra organisations level was rated as "good", whereas the connectivity with the public was assessed as "limited". The information richness reached a "fair" level in all of the information domain sub-tasks. This was due to the multiple tools used to share the information and because personnel were allocated to specialised information-sharing activities. The information reach both at inter and intra organisations level provided regular, simultaneous and selective communication, but it was affected by the various vulnerabilities previously identified, therefore it was judged as "limited".

Table 4.16 shows the assessment matrix for this domain. The success indicators pertinent to the Information Domain, namely (S_{I1})Connectivity, (S_{I2}) Information Richness and (S_{I3})Information Reach were targeted with a degree of fulfilment respectively of $F_{I1} =3.25$, $F_{I2}=3$, $F_{SI3}=2.33$. Assuming the same proportion relevance $\alpha_i=0.33$ for all of the success indicators in the Information Domain, the performance for the Information Domain has been evaluated according to Equation 3.2 at a "fair" level D_I=2.86

Table 4.16 - Information Domain Assessment Matrix.

INFORMATION DOMAIN		Applicable	Performance Level				Degree of Fulfilment
SUCCESS INDICATORS	S_{I1}) *Connectivity*	☑	4	4	2	3	3.25
	S_{I2}) *Information richness*	☑	3	3	N/A	3	3
	S_{I3}) *Information reach*	☑	2	2	N/A	3	2.33
			INTRA	**INTER**	**PUBLIC**	**DATA**	D_I
			SUB-TASKS				**2.86**

Applicable: Yes ☑, No ☐

Analysis of the Cognitive Domain during the Capital Quake Exercise

No particular tangible or intangible vulnerabilities were observed in this domain. Therefore, the vulnerability matrix for the Cognitive Domain was not completed. It is worth noting that the Capital Quake exercise role-play was taken seriously and the decision making was pro-active and result-driven. Individual situation awareness and training/experience were both assessed at a "fair" level of performance. There was an excellent understanding of the affected area, which enhanced quick response and decision-making processes. Decisions were made relying a lot on individual knowledge.

The success indicators pertinent to the Cognitive Domain, namely (S_{C1}) Individual Situation Awareness, (S_{C2})Level of Training and Experience and (S_{C3})Intangibles of Leadership and Unit Cohesion were targeted. Their respective degree of fulfilment respectively were $F_{C1}=3$, $F_{C2}=3$, $F_{C3}=2$. Therefore, assuming the same proportion relevance $\alpha_i=0.33$ for all the success indicators, the Cognitive Domain during the Capital Quake Exercise was performed at a "fair" level D_C=2.67. Table 4.17 summarises these results.

Table 4.17 - Cognitive Domain Assessment Matrix.

COGNITIVE DOMAIN		Applicability	Degree of Fulfilment
SUCCESS INDICATORS	S_{C1}) *individual situation awareness*	☑	3
	S_{C2}) *level of training and experience*	☑	3
	S_{C3}) *intangibles of leadership and unit cohesion*	☑	2
			D_C
			2.67

Applicable: Yes ☑, No ☐

Analysis of the Social Domain during Capital Quake Exercise

The assessment of this domain was mostly based on the activities during and after the exercise (debrief). Table 4.18 summarises this domain's assessment. The NZTA decision makers demonstrated very little concern about learning Civil Defence's priorities for this particular event. Therefore the responsivenessto the needs of emergency management agencieshas been judged as "fair" $F_{S1}=2$. On the other hand, a "fair" level of technical advice was provided to the emergency management agencies and lifeline groups $F_{S2}=3$. Regarding the coordination of actions with all involved agencies, it has been performed at a "fair" level: the third success indicator of the Social Domain resulted $F_{S3}=2.5$.

Assuming the same proportion relevance $\alpha_i=0.33$ for all the success indicators, the Social Domain during the Capital Quake Exercise was performed at a "fair" level D_S=2.5.

Table 4.18 - Social Domain Assessment Matrix.

	SOCIAL DOMAIN	**Applicability**	**Degree of Fulfilment**
SUCCESS INDICATORS	*S_{S1}) responsiveness to the needs of emergency management agencies*	☑	2
	S_{S2}) technical advice to leading emergency management agencies and lifeline groups	☑	3
	S_{S3}) coordination of actions with all involved agencies	☑	2.5
			D_S
	Applicable: Yes ☑, No ☐		**2.5**

Overall analysis

Considering the domain scores and assuming the same proportion relevance $\gamma_d=0.25$ for all domains, the performance is computed as *DM*=2.67 which means that the resilience of the decision making process is classified "fair" (adequate but some areas of dysfunction with limited adaptability; not effective in all circumstances; limited in solutions delivery; some feedback to involved organisations).

4.4 Ruaumoko Exercise 2008

The following subsections describe exercise activities and the analysis of the Ruaumoko Exercise 2008.

4.4.1 Background and activities

On the morning of 13th March 2008, various lifelines organisations, and Civil Defence groups participated in the Ruaumoko Exercise. This was organised as a Tier 4 national-level exercise (a joint local government and central government exercise) in accordance with the CDEM National Exercise Programme.

The exercise aimed to test New Zealand's all-of-nation arrangements for responding to a major disaster with particular focus on roles and responsibilities, arrangements and connections between local, regional, a national and international agencies.

The exercise included features typical of a full scale exercise, namely the simulation, resource assessment and deployment and damage assessment operations. For the NZTA National office, the challenge was how to cope with the massive evacuation planned for residents from the 5 Km radius blast zone. It was expected that the evacuation would cause significant congestion on motorways and State Highway (SH), SH 1 to Hamilton as well as SH 2 to the east. Another issue raised by the exercise was security (domestic and life support) of staff for both the NZTA and its suppliers, given the potential severity of the event.

Scenario

The assumed scenario was a volcanic eruption located in the inner Manukau harbour, which was expected to severely damage all land transport and to severely affect the North Island.

The scenario was based on a possible volcanic eruption somewhere in the Auckland Volcanic Field (Figure 4.11). The exercise commenced with the identification of precursor activity in the form of seismicity in the Auckland region during November 2007, such that planning meetings were required. In early 2008 unusual and sustained seismicity in the Auckland region prompted further attention until it was clear that a volcanic eruption was becoming imminent due to increasing seismicity. Earthquakes with intensity equal to Mercalli Intensity 6-7 were recorded more frequently in last 24-48 hours before the eruption.

The scenario included:

- Violent explosions caused by magma coming into contact with water; sound/pressure shock waves and complete devastation 1-3 km from vent;
- extremely violent base surge phenomenon with turbulent ground-hugging flows of ash/gas with a speed of 50-300 km/hr;
- ash fall;
- fountains in the vent area only lasting from 1 week to several months;
- lava flows crushing and burning everything in path in the area 1-10 km from vent and lasting from several weeks to several months;
- risk of widespread fire from hot ash, lava, or disrupted gas supply lines in the area 1-10 km from vent; and
- asphyxiating gases (CO, CO_2, HF, SO_2) accompanying lava flows in the area 1-5km from vent.

Physical impacts included damage to infrastructure and transportation utilities (including roads, ports, airports) and disruption to service of lifeline utilities (including electricity, gas, fuel, telecommunications, water). The damage from the eruption severely affected the ability of the remainder of the North Island to function and provide support to cope with refugees.

Road controlling authorities were asked to understand and simulate the reaction for the city population during the volcanic eruption in order to predict the level of panic, the direction of trips and the main purposes of trips. Self evacuation was the primary means of evacuation of the 60% of residents from the 5 Km radius blast zone. As a result Civil Defence moved 40% of people south and encouraged the 60% who were self evacuating to do the same. For the NZTA this created pressure on the motorway and SH 1 to Hamilton as well as SH 2 to the east, this was also escalated because this evacuation coincided with the normal evening rush hour peak flow

Figure 4.11 – Ruaumoko Exercise 2008 scenario: volcanic eruption located in the inner Manukau harbour. 3 km-radius devastation' zone 'and 5km-radius evacuation zone according to the Auckland Volcanic Contingency Plan.

Observed activities

Our research team members were distributed throughout 5 different locations (NZTA National Office in Wellington, Group Emergency Operations Centre, GEOC Auckland, NZTA Northcote Traffic Management; National GEOC Wellington and Evacuation Coordinator Support at Waitakere EOC) in order to comprehensively observe the exercise.

Our team observed that participating organisations had substantially different levels of awareness of the initial situation (impact, damage and vulnerabilities). Upon the introduction of initial injects, organisations faced a common issue, which was to predict how the volcanic eruption could affect the immediate and extended surrounding areas and weather these impacts aligned with assumptions made during previous planning. For instance, the NZTA National office showed very limited knowledge about affected area/assets, personnel, volcanic explosion consequences, and how traffic behaviour and traffic management should change in the face of this chaos. At the regional level, the NZTA relied on previous knowledge about the network, but it ignored the fact that evacuation patterns could be significantly different to those observed during other types of events. The Group Emergency Operations Centre (GEOC) in Auckland had access to a considerable amount of scientific information about the implications of the eruption, but it had a limited understanding of where to evacuate people and had different views on how traffic would be affected.

Situation awareness had considerable influence on how participants understood and proactively managed keystone vulnerabilities. For instance, the NZTA National Office did not take an active role during the exercise. The participating personnel were reluctant to get involved and decided to wait for requests from the NZTA Regional Office. Overall, it was observed that participating organisations were waiting for information rather than proactively seeking it. One exception was the Bay of Plenty(BOP) Regional Council that proactively engaged in seeking information on estimated arrival numbers and responding by directing the appropriate amount of evacuees to their respective welfare centres and feeding this information back to others.

The different perceptions of the initial situation were mostly due to difficulties in assimilating incoming information. Most participating organisations relied heavily on email communication, which would, in principle allow them to share text documents, maps and other various data about the event. Due to the magnitude of the event, participating organisations were swamped with very large and varied communication attempts. These eventually did not materialise into useful and reliable information that could support decision making. On the contrary, it was often observed that staff would spend significant time dealing with communication troubles (e.g. email sizes, spam filters and delays).

These difficulties were clearly reflected in the way the NZTA processed information. At the national level, staff decided to use as little information technology as they could, with the exception of email messages. At the regional level spreadsheets for logging phone calls and other acquired information were created during the exercise. NZTA regional staff recognised that they should not rely only on emails and phones as those could be unavailable in a real event. Nevertheless, no ideas on how to overcome these issues were discussed.

Various levels of adaptive capacity were observed. Mostly, the participating organisations managed to adjust as the exercise progressed. For example, the expansion of the eruption affected area prompted the NZTA regional office to quickly reorganise the traffic management arrangements. Nevertheless, the NZTA national office showed poor adaptive capability after initial communications with its regional office. The national office personnel avoided asking questions and/or requesting further information about response actions.

4.4.2 QDM analysis

The performance of participating SHOs was evaluated in terms ofInformation, Cognitive and Social domains.

The exercise aimed to analyse the performance of resource allocation using a volcanic eruption simulation, however not enough data was collected for the analysis of the task and subtasks identified in the Physical domain. No assessment matrix for the physical domain has been completed.Nevertheless we highlight vulnerabilities in the physical domain (Table 4.19), that impacted on the deployment of physical resources and on temporary traffic management.

Table 4.19 - Physical Domain Vulnerability Matrix.

PHYSICAL DOMAIN					
S_{P1}- Minimisation of road closures duration and variability					
Task/Sub-tasks				***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
DHR	**DPR**	**TTM**	**DAM**		
-	-	☑	-	No traffic modelling was implemented to understand the possible traffic scenarios	Lack of a comprehensive awareness of the traffic behaviour
-	☑	-	-	Lack of shelter, food, and water for evacuated people Insufficient fuel and extra vehicles to evacuate people	

Analysis of the Information Domain during Ruaumoko Exercise 2008

The intra-organisation communication analysed in this section refers to the communication undertaken among NZTA decision makers at the Wellington and Auckland offices. The inter-organisation communication analysed refers to the communication established between the aforementioned NZTA offices, the Waitakere EOC and the two GEOC involved. Communication with media and public was not performed.

Tables 4.20 and 4.21 summarise the outcomes in terms of tangible and intangible vulnerabilities and degree of fulfilment of the success indicators in the information domain.

Table 4.20 - Information Domain Vulnerability Matrix.

INFORMATIONDOMAIN					
				S_{I1}- Level of Connectivity	
Task/Sub-tasks					
INTRA	**INTER**	**MEDIA**	**PUBLIC**	***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
☑	☑	-	-	Communication by e mail inefficient and delayed many times	No ideas about possible alternatives in case of telecommunication unavailability
☑	☑	-	-	File size attached with email communication not reduced to the minimal	-
☑	☑	-	-	Very poor use of information technology to collect, analyse and share information	
☑	☑	-	-	No shift to phone due to e-mail miscommunications	-
				S_{I2}- Information richness	
INTRA	**INTER**	**MEDIA**	**PUBLIC**	***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
☑	☑	-	-	Too much use of acronyms, some unnecessary and misleading	
☑	☑	-	-	Lack of a consistent email protocol for emergency response	
				S_{I3}- - Information reach	
INTRA	**INTER**	**MEDIA**	**PUBLIC**	***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
☑	-	-	-		Poor and disorganised information sharing, performed with limited continuity
☑	-	-	-		Confused priority identification

Table 4.21 - Information Domain Assessment Matrix.

	INFORMATION DOMAIN	**Applicable**	**Performance Level**				**Degree of Fulfilment**
SUCCESS INDICATORS	*S_{I1}) Connectivity*	☑	2	2	N/A	2	2
	S_{I2}) Information richness	☑	3	3	N/A	3	3
	S_{I3}) Information reach	☑	2	3	N/A	2	2.33
			INTRA	**INTER**	**MEDIA PUBLIC**	**DATA**	***D_I***
			SUB-TASKS				**2.44**

Applicable: Yes ☑, No ☐

Analysis of the Cognitive Domain during the Ruaumoko Exercise 2008

The analysis of the Cognitive Domainaims to assess the decision maker's knowledge, capabilities, techniques, and procedures. Unfortunately, during the Ruaumoko Exercise 2008, our research team got the sense that some decision makers were not fully engaged with the exercise.This attitude resulted in them taking a passive role and in a lack of understanding of the evolving scenario and pending issues (Table 4.22). This may not be reflective of their potential performance in responding to a real event. Considering the observed tangible and intangible vulnerabilities the Cognitive Domain was assessed as shown in Table 4.23.

Table 4.22 -Cognitive Domain Vulnerability Matrix.

COGNITIVE DOMAIN

S_{C1} - individual situation awareness

Cognitive Elements			***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
Scenario Perception	**Understanding of Needs**	**Future Projection**		
☑	-	☑	-	Lack of awareness about volcanic explosion consequences; affected areas; impact on traffic behaviour
☑	-	☑	-	Lack of understanding about dimension and criticality of the event
-	☑	-	-	Lack of awareness about available personnel and assets

S_{C2} - level of training and experience

Cognitive Elements			***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
Scenario Perception	**Understanding of Needs**	**Future Projection**		
☑	☑	☑		Lack of knowledge about vulnerability analysis and impact scenarios available in NZ to understand the potential impact of volcanic risk

S_{C3} - intangibles of leadership and unit cohesion.

Cognitive Elements			***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
Scenario Perception	**Understanding of Needs**	**Future Projection**		
☑	☑	☑		Passive role during the exercise; reluctance to get involved and be proactive

Table 4.23 - Cognitive Domain Assessment Matrix.

	COGNITIVE DOMAIN	Applicability	Degree of Fulfilment
SUCCESS INDICATORS	*S_{C1}) individual situation awareness*	☑	2
	S_{C2}) level of training and experience	☑	3
	S_{C3}) intangibles of leadership and unit cohesion.	☑	2
			D_C
	Applicable: Yes ☑, No ☐		**2.33**

Analysis of the Social Domain during the Ruaumoko Exercise 2008

The quality of decision making in the Social Domain is assessed by investigating the responsiveness to the needs and the technical advice provided to emergency management agencies and the coordination of actions with all involved agencies. No relevant vulnerabilities were observed for the Social domain, which was performed at a "*fair*" level. Meetings between decision makers of the different agencies took place frequently. A scientific advisors group was formed, this group worked closely with GEOCs to provide injects and valuable advice. Table 4.24 presents the assessment matrix for the Social Domain.

Table 4.24 - Social Domain Assessment Matrix.

	SOCIAL DOMAIN	Applicability	Degree of Fulfilment
SUCCESS INDICATORS	*S_{S1}) responsiveness to the needs of emergency management agencies*	☑	3
	S_{S2}) technical advice to leading emergency management agencies and lifeline groups	☑	3
	S_{S3}) coordination of actions with all involved agencies	☑	2
			D_S
	Applicable: Yes ☑, No ☐		**2.67**

Overall analysis
Considering the domain scores and assuming the same proportion relevance $\gamma_d = 0.25$ for all domains, the performance is computed as *DM*=2.48 which means that the resilience of the decision making process is classified "fair" (adequate but some areas of dysfunction with limited adaptability; not effective in all circumstances; limited in solutions delivery; some feedback to involved organisations).

4.5 Mount Ruapehu Volcanic Eruption Event

The following subsections present the description and the analysis of the decision making process during the Mount Ruapehu Volcanic Eruption event.

4.5.1 Background and activities
On 25th September 2007, the Ruapehu Volcano, located in the New Zealand's North Island, erupted. According to the Ministry of Civil Defence and Emergency Management, the eruption occurred without warning at 8:20pm and lasted for about ten minutes. As a precaution, the ski fields were closed the following day and sixty people from Aorangi and Ruapehu huts were evacuated. The adjacent State Highway was also closed until possible damage was assessed. The eruption was accompanied by magnitude M=2.9 ground shaking that lasted seven minutes. An injured climber was the only direct victim from the event.

The eruption prompted regional Police, Civil Defence and NZTA's regional contractors to activate emergency response procedures. The event received attention from international, national, regional and local media as well by government bodies.

The eruption caused some concern for the local population, who criticised authorities for a lack of communication. Rumours about a failure in the warning system were circulated. However, the Conservation Department Tongariro acting manager said that the alarm system had worked and the Police Area Commander advised that steps were taken to communicate with those in the region in accordance with the emergency response plan. The failure of the cell-phone text message alert occurred because the event created a magnitude M=2.9 earthquake, while the alert threshold is a magnitude M=3.4. Ruapehu's ski fields were expected to reopen on the day after the event, but they were re-opened three days after the event. Many tourists complained about the ski field closures, because the event happened in the middle of the busy school holiday period. No property damage was reported and roads were closed for damage assessment until 11 pm on the night of the event. The mountain's extreme unpredictability and potential for further eruptions highlighted the importance of having a good warning system in the region and well defined response procedures and plans.

Contractor's Experience
An interview was conducted at the Work Infrastructure's office at Taumarunui on the 26th September 2007. After the Mt. Ruapehu eruption Works Infrastructure were alerted via the after-hours emergency system (around 9:40 pm), Police informed NZTA personnel, who called Works Infrastructure's after-hours service and the responsible person on call. The decision was made to set up road blocks and signage while assessing the road conditions. State Highways SH 1, SH 46, SH 47, SH48, SH4 and SH 4 around the

mountain were closed (Figure 4.12). To do this, road blocks were located at Ohakune, Manunui, Waiouru and Rangipo (Figure 4.13).

A road block was also put in place at Manunui, but the section of SH 4 until National Park Village was not closed. In this section of road drivers were informed about the situation and asked to drive carefully. Eight light trucks with road management gear (signs, barriers, flashing lights) and 14 people were used to set up the road blocks which were moved from the local depots (Taumarunui and Raetihi and Turangi, see Fig. 4.13). The roads were re-opened at approximately 11:30 pm. Two staff were left at Turangi to monitor the situation over night.

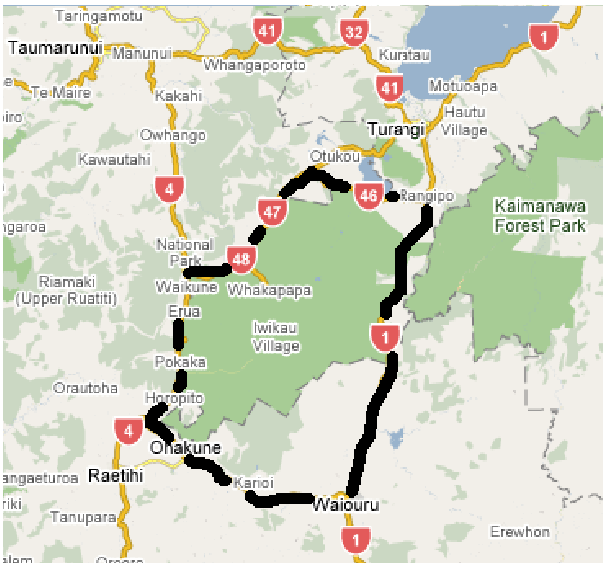


Figure 4.12 - Road Closures During the Event (highlighted in black).

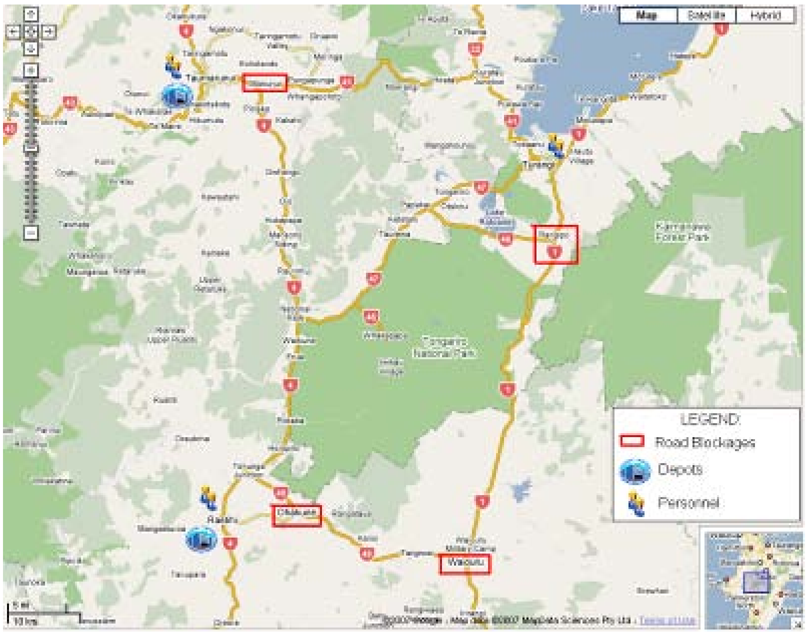


Figure 4.13 - Road Blocks, Depots and Personnel Location.

A driving assessment of the road network was completed which evaluated the condition of pavements, culverts, signage etc.) and included stopping for a visual assessment at critical points (mainly bridges) to check for possible damage. All costs involved in the response for Ruapehu's Eruption (mainly petrol and wages) were claimed from the NZTA.

New Zealand Police's Experience

An interview with the local Police Inspector was conducted at Taumarunui on the 29th September 2007. According to the Police Inspector, after the volcanic eruption the Police received a 111 phone call from a ski operator. It was noticed that the Eruption Detection System (EDS) did not work as the earthquake event accompanying the volcanic eruption was of the magnitude M=2.9. The EDS system is set up to be triggered by a M=3.4 event. The policeman recommended that the system must be set up to be triggered at a lower magnitude.

The decision to alert Police staff and close roads in the region of Mt. Ruapehu was made by the Police Inspector based on 17 years experience in the area and on lessons identified after the 1995 Mt. Ruapehu volcanic eruption. Hence, State Highways surrounding the Mt. Ruapehu were closed (SH 1, SH 46, SH 47, SH48 and SH4). Road blocks were put in place at Ohakune, Manunui, Waiouru and Rangipo.

The situation was managed using the principles from the Coordinated Incident Management System (CIMS). According to the standard procedures of CIMS, the Communication Centre of Taumarunui Police contacted the Contractor for the region (i.e. Works). The Police Inspector emphasized that the contractor was slow to respond to the incident (i.e. close the roads) due to the different locations of their resources on respect in the incident area. While waiting for the contractors, the police staff drove along the closed roads to check its condition. The NZTA and the consultant were not contacted by the Police, who coordinated the response with the contractor.

After the roads were closed and the contractor arrived in the area, the Police Inspector reached the Emergency Operation Centre that was established at Whakakapa, in the Department of Conservation (DoC) Office. A DoC staff member took the role of the Incident Controller using CIMS protocols. Local volunteers, who knew the region, were appointed to cover the different roles required by the CIMS structure.

The actions/decision making on the night of the event comprised the evacuation of 60 people from Iwikau Village to Hotel Chateaux. As the situation became clearer, an alternative option to go back to their accommodations was immediately granted. Also, roads were closed for assessment until the contractor had verified the road's safety condition. The last decision concerning the event was to close the ski fields until the situation was under control.

GNS Science, Institute of Geological and Nuclear Sciences, monitored and evaluated the volcano activity regularly until a final decision about safety could be made. On the day after the event, two meetings per day (4.30pm and 6.00pm) were scheduled until the situation could be considered as completely safe.

4.5.2 QDM analysis

This section presents the analysis of the Quality Decision Making processes after the Mount Ruapehu Volcanic Eruption, focusing on the Contractors' response. Due to the limited criticality of the event from the SHO point of view, the analysis is restricted to the assessment of the Physical and Information domains.

Analysis of the Physical Domain after the Ruapehu event

The Physical Domain during the event involved two major decisions: evacuation of people, and road closure for assessment. The evacuation process was easy to operate as few people were evacuated from Aorangi and Ruapehu huts to the Hotel Chateaux. Regarding the road closure, all the State Highways around the mountain were closed putting in place road blocks. Damage assessment was done visually by driving all of the possible affected roads and by stopping at most critical sections (e.g. bridges) for comprehensive evaluation. The road closures and assessments were initially operated by the local Police as contractor resources were spread around different locations in respect to the incident area.

The road assessment was conducted a second time by the contractor driving through the network and stopping at possible damaged road assets (e.g. pavement, culverts, signage) and at critical links (identified mainly with bridges).

Table 4.25 summarises the vulnerabilities that affected the decision making process in the physical domain.

Table 4.25 - Physical Domain Vulnerability Matrix after Ruapehu event.

PHYSICAL DOMAIN

S_{P1} - Minimisation of road closures duration and variability

Task/Sub-tasks				**Tangible Vulnerabilities**	***Intangible Vulnerabilities***
DHR	**DPR**	**TTM**	**DAM**		
☑	☑	☑	☑	different location of HR and PR on respect to incident Area	

S_{P2} - maximisation of accessibility to strategic services and places

Task/Sub-tasks				***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
DHR	**DPR**	**TTM**	**DAM**		
		☑		Lack of redundancy in the network	

S_{P3} - minimization of response and recovery costs

Task/Sub-tasks				***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
DHR	**DPR**	**TTM**	**DAM**		
					-

Despite these vulnerabilities, it is assessed that the deployment of physical and human resources during Mount Ruapehu event was operated at a "fair" level D_P=3 as shown in Table 4.26.

Table 4.26 - Physical Domain Assessment Matrix after Mount Ruapehu event.

	PHYSICAL DOMAIN	Applicability		Degree of fulfilment
SUCCESS INDICATORS	*S_{P1}) Minimisation of road closures duration and variability*	☑		3
	S_{P2}) Maximisation accessibility to strategic services and places	☑		3
	S_{P3}) Minimisation response and recovery costs	☑		3
				D_P
	Applicable: Yes ☑, No ☐			**3**

Analysis of the Information Domain during Mount Ruapehu event

The inter-organisation communication herein analysed refers to the communication undertaken among NZTA decision makers, its consultant (Opus) and the contractor (Works). The intra-organisation communication analysed refers to the communication established between the aforementioned organisations and the local Police.

The alarm and the communication process started with the Police who were alerted by the public. The Police informed NZTA about the event, and NZTA shared the information with Works. In the particular case of Mt. Ruapehu eruption, the flow of information through NZTA call centre was judged unsatisfactory, with many steps along the information chain, increasing the potential for misinterpretations. However, during the event management, a direct information sharing process was established between the Police and the Contractor. It is worth noting that Opus did not have a direct involvement other than informing media and NZTA. Works reported back to the Consultant (Opus) just to let them know that the situation was under control and no damage was observed. This is a procedure normally adopted in minor events.

Information about closure times and response plans acquired from the Contractor, the local Police, the Civil Defence and the Ministry of Conservation did not completely match. This was interpreted as a low level of connectivity between the organisation and as clear sign of poor information reach.

Table 4.27 summarises the tangible and intangible vulnerabilities that affected the success indicators considered in the information domain and Table 4.28 provides the expert judgment about their degree of fulfilment.

Table 4.27 - Information Domain Vulnerability Matrix after Mount Ruapehu event.

INFORMATIONDOMAIN					
S_{I1}- Level of Connectivity					
Task/Sub-tasks				***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
INTRA	**INTER**	**MEDIA**	**PUBLIC**		
-	☑	-	-	-	Lack of flexibility in the information chain
S_{I2} - Information richness					
INTRA	**INTER**	**MEDIA**	**PUBLIC**	***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
☑	☑	-	-	Lack of an organised methodof recording and sharing information	-
S_{I3} - Information reach					
INTRA	**INTER**	**MEDIA**	**PUBLIC**	***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
-	☑	-	-	Mismatching information between organisations (police and contractor)	-

The success indicators pertinent to the Information Domain, namely S_{I1} Connectivity, S_{I2} Information Richness and S_{I3} Information Reach were assessed with a degree of fulfilment respectively of F_{I1} $=2.33$, $F_{I2}=3$, $F_{SI3}=2.67$. Assuming the same proportion relevance $\alpha_i=0.33$ for all the success indicators in the Information Domain, the performance for the Information Domain was evaluated according to Equation 3.2 as “fair” D_I=2.67.

Table 4.28 -Information Domain Assessment Matrix after Mount Ruapehu event.

INFORMATION DOMAIN		**Applicable**	**Performance Level**				**Degree of Fulfilment**
SUCCESS INDICATORS	*S_{I1}) Connectivity*	☑	2	3	N/A	2	2.33
	S_{I2}) Information richness	☑	3	3	N/A	3	3
	S_{I3}) Information reach	☑	3	2	N/A	3	2.67
			INTRA	**INTER**	**PUBLIC**	**DATA**	**D_I**
Applicable: Yes ☑, No ☐			**SUB-TASKS**				**2.67**

Overall analysis
Considering the domain scores and assuming the same proportion relevance $\gamma_d = 0.25$ for all domains, the performance is computed as *DM*=2.84 which means that the resilience of the decision making process is classified as “fair” (adequate but some areas of dysfunction with limited adaptability; not effective in all circumstances; limited in solutions delivery; some feedback to involved organisations).

4.6 Flooding along SH1, Kaikoura

The following subsections present the description and the analysis of the decision making process during flooding events that resulted in the closure of State Highway 1 near Kaikoura.

4.6.1 Background and activities
During late July 2008, a series of storm events affected New Zealand. The South Island was badly affected and in particular a Civil Defence Emergency was declared in the Marlborough District Council region.

Dozens of people were evacuated from their homes and a camping ground was set up in Picton because of flooding. Swollen streams were made worse by a high tide and sandbags were used to try and kept rising water from houses. In Nelson, a major water pipeline was damaged by falling trees and authorities asked residents to minimise water use as a result. About a dozen residents from Sefton, north of Christchurch, had also been evacuated because of flooding and moved to a local school hall.

Flooding forced the closure of State Highway 1 between Blenheim and Kaikoura, and emergency services warned about flooding dangers in many parts of Canterbury and Marlborough, including Christchurch city. In reality few roads in Christchurch and the Waimakariri area experienced surface flooding. The situation was worsened by extreme winds which were lifting roof tiles and scattering branches and other debris throughout neighbourhoods.

The decision process relevant to the management of the State Highway network in the South Island was observed at Opus office in Christchurch, over approximately seven hours on the 31st of July 2008.

4.6.2 QDM Analysis
This section presents the analysis of the Quality Decision Making processes after the Floods in SH1 Kaikoura, focusing on the Consultant’s response. Due to limitations in availability of observation staff, the analysis does not include the assessment of the Physical Domain, which would require several observers at the event location.

Analysis of the Physical Domain after Flooding along SH1
For this specific event, Contractors managed specific incidents in the field and available resources were sufficient to meet demand, however, staff shifts were not implemented. There was no consideration for the possible need to reallocate staff due to stress/tiredness and private matters.

The information and data collected about the Physical Domain were not sufficient for filling in the vulnerability and assessment matrices.

Analysis of the Information Domain after Floods in SH1

Activities regarding information management were uniquely performed by the Consultants who had to report to NZTA on a frequent basis. The communication with NZTA was performed mainly relying on internet connection. The Consultants were the communication link between NZTA and people on the field. Information was received from field personnel (either Consultant or Contractor staff) by phone (mostly using cell phones). RTs were seldom used and information was shared only in spoken and/or written forms.

Information was collected and processed, including writing on "post-it" stickers and "pinning" them on a hard copy map on the wall. Over the course of the event, the map was frequently updated and all cleared damage was recorded on the side of the map. Miscommunications were seldom observed. The NZTA was in charge of public information. The NZTA website (http://www.transit.govt.nz/) was used efficiently to inform the public about the event and its impact on roads and traffic.

Despite the few physical vulnerabilities observed (Table 4.29), five members of the decision making team efficiently received, processed and shared information.

Table 4.29 - Information Domain Vulnerability Matrix after Floods in SH1.

INFORMATIONDOMAIN					
S_{I1}- Level of Connectivity					
Task/Sub-tasks				***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
INTRA	**INTER**	**MEDIA**	**PUBLIC**		
☑	☑	-	-	Communication entirely dependent on internet and phone (lack of alternative methods of communication)	Only one person retains all the exchanged info
S_{I2}- Information richness					
INTRA	**INTER**	**MEDIA**	**PUBLIC**	***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
☑	☑	-	-	Lack of standardised ways to receive, log and update information	-
☑	☑	-	-	Limited use of IT capabilities (only RAMM Data Base and a video record of the network)	-
S_{I3}- Information reach					
INTRA	**INTER**	**MEDIA**	**PUBLIC**	***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
-	-	-	-	-	-

Table 4.30 shows the assessment matrix for the Information domain. The success indicators pertinent to the Information Domain, namely S_{I1} Connectivity, S_{I2} Information Richness and S_{I3} Information Reach were assessed with a degree of fulfilment respectively of F_{I1} *=3.67,* F_{I2}*=2.5,* F_{I3}*=2.75*. Assuming the same proportion relevance

$\alpha_i=0.33$ for all the success indicators in the Information Domain, the performance for the Information Domain has been evaluated according to Equation 3.2 at a "fair" level D_I=2.97.

Table 4.30 - Information Domain Assessment Matrix after Floods in SH1.

INFORMATION DOMAIN		Applicable	Performance Level				Degree of Fulfilment
SUCCESS INDICATORS	*S_{I1}) Connectivity*	☑	4	3	4	N/A	3.67
	S_{I2}) Information richness	☑	2	2	4	2	2.5
	S_{I3}) Information reach	☑	4	2	3	2	2.75
			INTRA	**INTER**	**PUBLIC**	**DATA**	**D_I**
Applicable: Yes ☑, No ☐			**SUB-TASKS**				**2.97**

Analysis of the Cognitive Domain after Floods in SH1

All members of the decision making team had good understanding of their duties. Decisions were achieved through understanding and expertise (e.g. time to reopen the roads and to clear debris was estimated).

The consultants had their own specific knowledge about the region and its needs and how to meet these. An intangible vulnerability was that inexperienced or new staff could not be used to help in managing the event, because structured knowledge or procedures were not properly available.

Table 4.31 shows the assessment matrix for the Cognitive domain. The success indicators pertinent to the Cognitive Domain, namely S_{C1} Individual Situation Awareness, S_{C2} Level of Training and Experience and S_{C3} Intangibles of Leadership and Unit Cohesion were assessed with a degree of fulfilment respectively of $F_{C1}=4$, $F_{C2}=3$, $F_{C3}=4$. Assuming the same proportion relevance $\alpha_i=0.33$ for all the success indicators the performance was evaluated according to Equation 3.2 at a "good" level D_C=3.67.

Table 4.31 - Cognitive Domain Assessment Matrix after Floods in SH1.

	COGNITIVE DOMAIN	Applicability	Degree of Fulfilment
SUCCESS INDICATORS	S_{C1}) *individual situation awareness*	☑	4
	S_{C2}) *level of training and experience*	☑	3
	S_{C3}) *intangibles of leadership and unit cohesion.*	☑	4
Applicable: Yes ☑, No ☐			**D_C** **3.67**

Analysis of the Social Domain during Floods in SH1

Regarding the coordination of actions, the team observed a good level of self-synchronisation at the field level. Contractors were able to manage specific instances on the field and to prioritise the available plant and machinery that was sufficient to cover all the resources required by the event.

Table 4.32 shows the assessment matrix for the Social domain. The success indicators pertinent to the Social Domain, namely (S_{S1})Responsiveness to the Needs of Emergency Management Agencies, (S_{S2})Technical Advice to Leading Emergency Management Agencies and Lifeline Groups and (S_{S3})Coordination of Actions with all Involved Agencies were assessed with a degree of fulfilment respectively of $F_{S1}=2$, $F_{S2}=2$, $F_{S3}=3$. Assuming the same proportion relevance $\alpha_i=0.33$ for all the success indicators, the performance was evaluated according to Equation 3.2 at a “fair” level D_I=2.33.

Table 4.32 -Social Domain Assessment Matrix after Floods in SH1.

	SOCIAL DOMAIN	Applicability	Degree of Fulfilment
SUCCESS INDICATORS	S_{S1}) *responsiveness to the needs of emergency management agencies*	☑	2
	S_{S2}) *technical advice to leading emergency management agencies and lifeline groups*	☑	2
	S_{S3}) *coordination of actions with all involved agencies*	☑	3
Applicable: Yes ☑, No ☐			**D_S** **2.33**

Overall analysis
Considering the scores of the three analysed domains, the performance of the decision making process after Floods in SH1 real event, has resulted in *DM*=2.99. This means that the decision making process is classified as "*fair"* (adequate but some areas of dysfunction with limited adaptability; not effective in all circumstances; limited in solutions delivery; some feedback to involved organisations), but borders on the threshold of being classified as "good".

4.7 Flooding along SH2, Matata

The following subsections present the description and the analysis of the decision making process during the Flooding along SH2, Matata.

4.7.1 Background and activities
Matata is a seaside village of approximately 500 people in the Bay of Plenty region, North Island of New Zealand. Matata is located halfway between Whakatane, which is a forestry industry region, and Tauranga, where one of the busiest ports of New Zealand is located. Whakatane and Tauranga are connected by railway and road, with the State Highway SH2 being the most important part of the network, with heavy traffic observed daily in both directions.

On the evening of May 16th, 2005, the MetService issued a heavy rain warning to the local (Whakatane District Council) and regional authorities (Bay of Plenty Regional Council). They also notified all infrastructure and lifeline providers in the region, including the NZTA offices in Hamilton and Gisborne.

In the early hours of May 17th the NZTA area engineer and the Consultant engineer, who were coincidently meeting together in Whakatane, received initial reports from the local community and NZTA Contractors about partial road closures on SH 2 due to water on the road surface and localized slips blocking traffic.

An additional contracting crew was mobilised to the location of the road closure via mobile phone. SH2 was reopened approximately 12 hours after the first warnings were received. The poor weather conditions continued overnight however and during road inspections the following day (May 18th) the NZTA area engineer and Consultant engineer together, actually witnessed the washout of one bridge embankment.

Subsequent reports from road users about more washouts prompted the NZTA area engineer and the Consultant engineer to hire a helicopter in Whakatane and conduct a fly-over inspection. Immediately after the inspection, complete road closure of SH 2 was declared and supplementary personnel and equipment from the NZTA Contractor were requested. Up to that point in time, communications and exchange/sharing of data and information were very limited. The NZTA Headquarters in Wellington had been informed of the road closure, without any estimation of the reopening time. The area engineer liaised with local and regional councils sharing the same level of information available to NZTA Headquarters. Press releases were made to the media about the road closures. Interaction between the NZTA area engineer and the Consultant engineer occurred almost instantly as both were *in situ* coordinating and making decisions together.

The Consultant engineer, originally based in Matata, reported back to his office in Whakatane via mobile phone communications and using his deputy road technician.

Consultant's reports were used to produce maps of road closures and initial estimates of damage and costs. Transmitted data comprised very general instructions referring to road assets per kilometre. No specific data on previous road asset conditions (e.g. location and characteristics of roading elements) were readily accessible to the involved parties (NZTA, Consultant and Contractors).

On the afternoon of May 18th a Civil Defence Emergency was declared by the Western Bay of Plenty Emergency Management Office. Subsequently the Whakatane District Council also declared a state of local emergency for the Edgecumbe-Tarawera Ward (Matata Township) on the evening of the 18th May. Late that night, a band of intense rain passed over the catchments behind Matata and triggered many landslips (debris avalanches), which destroyed 27 homes and seriously damaged 87 properties Initial response actions commenced immediately.

Resources were already available in the area due to earlier road closures. However, a major drawback was a lack of suitable gear for operating during the night because batteries for the spotlights available were faulty. Communications relied almost entirely on cellular mobile telephones and radio telephones (RT's). All involved parties (NZTA engineer, Consultant and Contractor) were using Telecom cell phones, which had good coverage in the area. Conversely, the research team had some difficulties contacting the response parties, because our Vodafone cell phones had very poor coverage in some areas of the affected region. Radio communication was largely used between the contractor's crew. Localised communications over short distances, such as for the direction of machinery and personnel were very well suited to low frequency RT communications. Nevertheless, during times of confusion, face-to-face communications proved to be the most effective means of getting activities underway.

The landslips in Matata and complete closure of SH2 created difficulties in transporting equipment and personnel from Tauranga. Alternative routes through mountainous areas had to be used, which incurred delays in the response actions. Nevertheless, the contractor mobilised a considerable number of personnel (over 50 people) and machinery (25 heavy load trucks, 10 diggers, 4 bulldozers, 1 grader, etc).

On the 20th, SH2 partially reopened overnight (5pm to 5am) for use by heavy and commercial traffic only. On 30th May, 14 days after the initial closures, SH2 was completely reopened to general traffic. At that point in time, the NZTA had no specific assessment of road repair costs, but approximate estimates ranged from 2.5 to 5 million dollars. Consultants recorded daily information on damage and resource deployment. This mainly consisted of a list of damaged assets, their priorities and recommended treatment. This information was shared with the Contractor using paper.

4.7.2 QDM Analysis

This section presents the analysis of the Quality Decision Making processes after Flooding along SH2, Matata, focusing on the Contractors' and Consultants` response. Due to the presence of one research team member on the field during several phases of the emergency management and response, it was possible for this event, to analyse all of the domains of the decision making process.

Analysis of the Physical Domain duringFlooding along SH2, Matata

The 2005 Matata township flood was a small-medium emergency event in contrast to the previous year's events that caused widespread damage in the Bay of Plenty. The 2005 event was mostly confined to the Matata township and its nearby coastal area, which comprises a portion of SH2 known as the "Matata Straight" (approximately 5 km of road).

As the emergency response was concentrated in very specific parts of the roading infrastructure, the NZTA area engineer and Consultant coordinated involved organisations and their resources locally.

Table 4.33 shows the tangible vulnerabilities that affected the physical domain decision-making process.

Table 4.33 -Physical Domain Vulnerability Matrix after Flooding along SH2, Matata.

PHYSICAL DOMAIN					
S_{P1} - Minimisation of road closures duration and variability					
Task/Sub-tasks				***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
DHR	**DPR**	**TTM**	**DAM**		
☑	☑	☑	☑	No suitable gear for operating during the night because batteries for the spotlights available were faulty	-
☑	☑	☑	☑	Contractors did not know the exact location and prior characteristics of roading elements	-
S_{P2} - maximisation of accessibility to strategic services and places					
Task/Sub-tasks				***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
DHR	**DPR**	**TTM**	**DAM**		
☑	☑	☑	☑	The landslips in Matata and complete closure of SH2 created difficulties in transporting equipment and personnel from Tauranga in order to effect repairs	-
S_{P3} - minimization of response and recovery costs					
Task/Sub-tasks				***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
DHR	**DPR**	**TTM**	**DAM**		
☑	☑	☑	☑	Alternative routes through mountainous areas had to be used, which incurred delays in the response actions	-

Table 4.34 shows the assessment matrix for the Physical domain. The success indicators pertinent to the Physical Domain, *Minimisation of road closures duration and variability, S_{P1}, Maximisation accessibility to strategic services and places, S_{P2}, Minimisation response and recovery costs, S_{P3}* were assessed with a degree of fulfilment respectively of *F_{P1}=3, F_{P2}=2, F_{P3}=3*. Assuming the same proportion relevance *α_i=0.33* for all the success indicators in the Physical Domain, the performance for the Physical Domain has been evaluated according to Equation 3.2 at a “fair” level D_P=2.67.

Table 4.34 - Physical Domain Assessment Matrix after Flooding along SH2, Matata.

	PHYSICAL DOMAIN	**Applicability**	**Degree of Fulfilment**
SUCCESS INDICATORS	*S_{P1}) Minimisation of road closures duration and variability*	☑	3
	S_{P2}) Maximisation accessibility to strategic services and places	☑	2
	S_{P3}) Minimisation response and recovery costs	☑	3
			D_P

Applicable: Yes ☑, No ☐ **2.67**

Analysis of the Information Domain afterFlooding along SH2, Matata

Observation of communications and data/information exchange/sharing during the Matata events indicates that informal linkages and assessment were the dominant form of communications. An important issue observed during the case study was the potential fragility in a larger scale event of the communication systems used to manage the response. The predominant means of communication for the SHO was either face-to-face meetings or by cellular/mobile telephones. The fact that both the Contractor and Consultant representatives were together at the time the event escalated simplified subsequent communications significantly and allowed for shared decision-making. The RT network was also used for communications during the response; however it was only used for communications within organisations. In a large scale emergency event the cellular/mobile phone network is likely to be an unreliable means of communication; cell phone towers may be damaged, there may be poor network coverage at the site; or the network may become overloaded as the volume of calls made by the general public escalates during times of crisis.

Regarding data management, the information system used (RAMM) was perceived as not suitable for coping with the dynamic nature of such an event. RAMM is largely employed in asset management and maintenance of State Highways, therefore it is programmed and organised to support medium term decision-making. During an emergency event, RAMM provides limited information value, because damage may have altered the whole arrangement and location of roading elements. For example, the contractor may want to replace a stop sign using RAMM-kilometre reference, but the road alignment has been completely changed due to mud and debris and it becomes impossible to identify sign posts and any other references required to perform the original task. One other example indicating RAMM's deficiency in supporting emergency decision making is that during the observed deployment of heavy machinery, no data was retrieved from RAMM in order to indicate, for example, the original grading and alignment. Table 4.35 summarises the aforementioned tangible vulnerabilities.

Table 4.35 -Information Domain Vulnerability Matrix after Floods in SH2 Matata.

INFORMATIONDOMAIN					
S_{I1}- Level of Connectivity					
Task/Sub-tasks				***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
INTRA	**INTER**	**MEDIA**	**PUBLIC**		
☑	☑	☑	☑	Limited cell phone coverage in some areas	
S_{I2}- Information richness					
INTRA	**INTER**	**MEDIA**	**PUBLIC**	***Tangible Vulnerabilities***	***Intangible Vulnerabilities***
☑	☑	-	-	Available information system not suitable for coping with the dynamic nature of an emergency event	

Table 4.36 shows the assessment matrix for the Information domain. The success indicators pertinent to the Information Domain, namely S_{I1} Connectivity, S_{I2} Information Richness and S_{I3} Information Reach were assessed with a degree of fulfilment respectively of $F_{I1}=4$, $F_{I2}=3$, $F_{I3}=3$. Assuming the same proportion relevance $\alpha_i=0.33$ for all the success indicators in the Information Domain, the performance for the Information Domain has been evaluated according to Equation 3.2 at a "verygood" level D_I=3.33.

Table 4.36 - Information Domain Assessment Matrix after Floods in SH2 Matata.

	INFORMATION DOMAIN	Applicable		Degree of fulfilment
SUCCESS INDICATORS	*S_{I1}) Connectivity*	☑		4
	S_{I2}) Information richness	☑		3
	S_{I3}) Information reach	☑		3

Applicable: Yes ☑, No ☐

D_I

3.33

Analysis of the Cognitive Domain afterFloods in SH2 Matata

Decision makers` previous knowledge about the area and the assets was largely used for the management of the floods in SH2 Matata. Moreover, "common sense" was constantly used to compensate for a lack of information. Both of these elements have been positively judged when assessing the cognitive domain (Table 4.37). Obviously, despite the recognised importance of previous knowledge and common sense, it is worth highlighting the need to formalise these characteristics in order to be able to efficiently use them to solve more complex problems such as would be the case in a larger scale event.

Table 4.37 - Cognitive Domain Assessment Matrix after Floods in SH2 Matata.

	COGNITIVE DOMAIN	Applicability		Degree of Fulfilment
SUCCESS INDICATORS	*S_{C1}) individual situation awareness*	☑		4
	S_{C2}) level of training and experience	☑		4
	S_{C3}) intangibles of leadership and unit cohesion.	☑		3

Applicable: Yes ☑, No ☐

D_C

3.67

Analysis of the Social Domain afterFloods in SH2 Matata

Overall, the management of the response and recovery observed from the Matata event was very effective. The people on the ground knew each other very well, and this helped to facilitate shared decision making and communications. In a larger scale event however, those managing the response and recovery may not know each other so well, particularly where external people are brought into the area to support local teams. In a larger scale event, where more organisations are involved and the situation is more complex, there is likely to be a need for more formal structures for planning and co-ordination. Table 4.38 shows the assessment matrix for the Social domain that was performed at a "good" level D_S=4.

Table 4.38 - Social Domain Assessment Matrix after Floods in SH2 Matata.

	SOCIAL DOMAIN	Applicability	Degree of fulfilment
SUCCESS INDICATORS	*S_{S1}) responsiveness to the needs of emergency management agencies*	☐	N/A
	S_{S2}) technical advice to leading emergency management agencies and lifeline groups	☐	N/A
	S_{S3}) coordination of actions with all involved agencies	☑	4
			$\boldsymbol{D_S}$
	Applicable: Yes ☑, No ☐		**4**

Overall analysis

Considering the domain scores and assuming the same proportion relevance γ_d *=0.25* for all domains, the performance is computed as *DM*=3.42 which means that the resilience of the decision making process is classified as "good" (mostly coordinated; mostly adaptable; effective in most circumstances; comprehensive in solutions delivery; comprehensive feedback to involved organisations).

5 Comparative Analysis

This section presents a comparative examination of the quality of decision-making results. The aim is to highlight the strengths and weaknesses currently affecting the decision making approaches adopted by SHOs during crisis events. The next three sub-sections summarise the observed vulnerabilities and the overall QDM analysis.

5.1 Key Vulnerabilities affecting extreme event decision making

Due to the different nature of exercises and events, the vulnerabilities are presented separately.

Vulnerabilities recorded during Simulation Exercises
Even though no significant vulnerabilities were observed in the Social Domain, several issues were quite common amongst the Physical, Information and Cognitive domains. Annex D shows tables summarising all of the vulnerabilities for each observation domain. The most common were:

- Physical Domain: insufficient and/or difficulties in deploying human and physical resources;
- Information Domain: lack of alternative means of communications, lack of dedicated personnel to collect process, information sharing and an inability of decision makers to access intra-organisation information; and
- Cognitive Domain: lack of individual situation awareness combined with deficiencies in decision makers' training and experience.

Vulnerabilities recorded during Real Events
During the observation of real events our team members were not located in the main Emergency Operations Centre and so were unable to record social and cognitive vulnerabilities. However we managed to identify the following issues in other domains:

- Physical Domain: the response activities were delayed because of the lack of redundancy in the network or more importantly because of the lack of awareness or unwillingness to use alternative routes, which would facilitate temporary traffic management; and
- Information Domain: inadequate information systems, lack of alternatives methods of communication, lack of dedicated personnel to collect, process and share information, and the impossibility for all the decision makers to have access to intra-organisation information.

Comparatively, similar vulnerabilities were identified in both exercises and events. This may indicate that decision makers tend to act quite similarly in both contexts. One exception is that in events vulnerabilities are observed in specific problems. For example, temporary traffic management is usually a common problem affecting the physical domain.

In real events, involved SHOs are under pressure to achieve immediate and localised solutions and, they tend to make decisions without considering the network implications. On the other hand, during exercises participants have the opportunity to conceptualise and rationalise various action scenarios, but are unable to test *in situ* allocation of resources. Similar observations could be drawn in terms of information sharing needs and procedures during exercises and events.

5.2 Comparative Analysis of Decision Making Quality Scores

The overall performance of SHOs is within the *Good* and *Limited Resilience* ranges. As graphically represented in Figure 5.1 and summarised in Tables 5.1 and 5.2, each event and simulation exercise presented different characteristics in terms of decision making performance. This was mostly due to the consistently high performance observed in the Cognitive and Social Domains, with a lower level (but still satisfactory) in the Physical and Information domains. SHOs were generally capable of providing a “fair” level of responsiveness and technical advice, as well as showing good individual awareness.

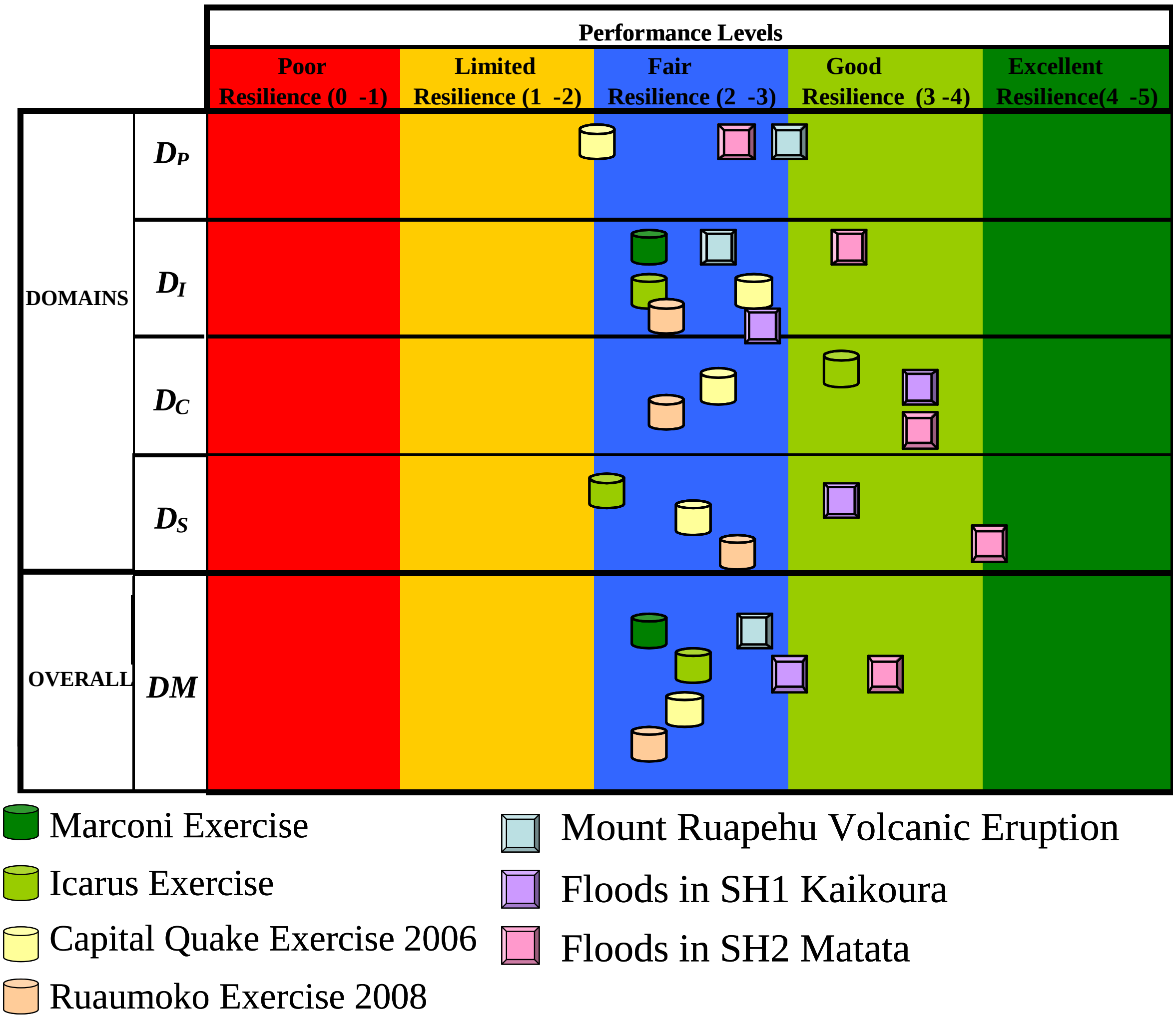


Figure 5.1 – Decision making performance level for observed exercises and events.

Table 5.1 -Decision Domain Scores and Decision Making global scores for simulation exercises.

	Domain				
	Physical	**Information**	**Cognitive**	**Social**	**Overall**
Exercises	***D_P***	***D_I***	***D_C***	***D_S***	***DM***
Marconi Exercise		2.33			**2.33**
Icarus Exercise		2.33	3.33	2	**2.55**
Capital Quake 2006	2	2.86	2.67	2.5	**2.51**
Ruaumoko Exercise 2008	-	2.44	2.33	2.67	**2.48**
Average score	**2**	**2.49**	**2.78**	**2.39**	**2.47**

Table 5.2 -Decision Domain Scores and Decision Making global scores for real events.

	Domain				
	Physical	**Information**	**Cognitive**	**Social**	**Overall**
Real Events	***D_P***	***D_I***	***D_C***	***D_S***	***DM***
Mount Ruapehu Volcanic Eruption	3	2.67	-	-	**2.84**
Floods in SH1 Kaikoura	-	2.97	3.67	2.33	**3**
Floods in SH2 Matata	2.67	3.33	3.67	4	**3.42**
Average score	**2.84**	**2.99**	**3.67**	**3.17**	**3.08**

SHOs performed slightly better in real events than in simulation exercises. The average scores show that the performance in real events reached a “Good Resilience” level, whereas simulation exercises were mostly at the “Fair Resilience” level. As shown in Figure 5.2, SHOs performed better in real events for all observation domains. The team observed a good individual awareness and high levels of training and experience. However there was limited leadership and cohesion, when managing real events.

On one hand, these results demonstrate that SHOs have strong technical and leadership capabilities, which are clearly and efficiently used in real events. On the other hand, these results could be perceived as showing an indication of lack of experience and leadership when non-senior staff are subject to pressure and complex situations. A plausible reason for the different performances may be signs of only partial commitment shown by some exercise participants. SHO personnel involved in real crises performed very well under pressure.

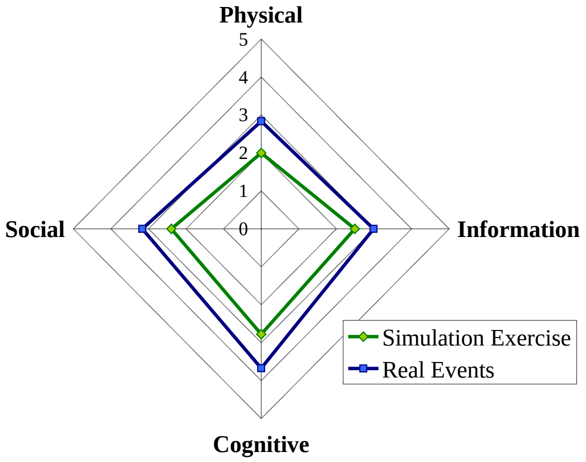


Figure 5.2 - Average values of the Decision Domain Scores resulting for simulation exercises and real events.

The best performance occurred in the Matata Flooding event. A combination of highly experienced staff, good timing/coordination and efficient usage of information were computed and analysed as high scores in the Cognitive, Social and Information domains. Even though the event created substantial pressure on all involved parties, SHOs managed to overcome difficulties and re-established partial network accessibility within a reasonable timeframe. This is appropriately reflected in the highest achieved scores as shown in Table 5.2.

Despite the performance in most exercises and events, the deficiencies associated with the Physical and the Information Domains are significant. In the Physical Domain, the scores shown in Tables 5.1 and 5.2 clearly show that improving resource allocation and optimisation needs to be addressed. Similarly, the Information Domain scores show that there is still limited coverage in information sharing process and that no information-sharing standards have been adopted so far. Nevertheless, it should be highlighted that SHOs have excelled in terms of both formal and informal connections.

6 Conclusions and Recommendations

This report introduced a novel approach to analysing the quality of SHO decision making. Based upon the combination of state-of-the-art knowledge about decision making theory, the QDM method was conceptualised and applied to several case studies of events and simulation exercises observed in New Zealand over the last 6 years. Above all, this report presents a diagnosis about how SHOs perform decision making activities.

The results of the QDM analysis indicate that SHOs are capable, experienced and competent in dealing with major disruptions or crises that may affect the State Highway Network of New Zealand. SHOs have achieved Good and Fair levels of resilience in decision making activities during emergency response events and exercises. Depending on the event or exercise, this means that SHOs can:

- Be mostly or partially coordinated;
- Be mostly or limited adaptable;
- Be effective or partially effective in most circumstances;
- Provide comprehensive or limited in solutions delivery; and
- Provide comprehensive or limited feedback to involved orgs.

Our analysis revealed that SHOs performed slightly better in real events than in simulation exercises. This difference in performance is mostly because exercises are used to expose junior staff to situations which they do not fully understand and/or have the experience to deploy and coordinate resources allocation.

SHO's major strengths were their ability to perceive, assess and act based upon experience and technical skills. This often took the form of extensive networking (informal and professional) with key individuals involved in emergency response. Senior SHO staff demonstrated high levels of situation awareness and leadership in various situations.

SHO's major decision making weaknesses during the emergency response are mostly related to resource allocation and information sharing. Most decisions were performed without clear and/or rationalised/structured processes supporting them. This was significantly affected by the fact that SHOs did not have decision making tools. Due to the level of complexity and the risky nature of events, decision making can be overwhelming; some decision makers could not grasp all of the potential response actions, implications and benefits/costs throughout all the emergency response stages. Also the lack of reliable and well presented information did not help those involved in the decision making process.

Based upon our experience throughout this project and with parallel work conducted over the last 5 years on improving the performance of SHOs, a list of recommendations is introduced. They include:

A. ***An extensive program to address the observed vulnerabilities:*** personnel involved in real events should be invited to discuss the observed vulnerabilities and assess whether they have already been addressed or whether further action is required. This would follow preparation and readiness actions towards extensive implementation of the measures;

B. ***The establishment of a continuous program of event and exercise observation using the proposed QDM method:*** this would comprise a set of designated observers who would participate in all upcoming events and exercises in order to further expand this report's findings. Over time, it is envisaged that a significant body of knowledge would be created and transferred to all SHOs around the country;

C. ***Decision making vulnerability matrix for use in exercise and event debriefs:*** this comprises the creation of a simple tool (vulnerability matrix) to record the strengths and weaknesses observed in decision making during emergency exercises and events. During major NZTA exercise debriefs, the decision making vulnerability matrix would diagnose how effective decision makers were against critical criteria, such as information sharing, physical resource deployment, and cognitive and social awareness. This would allow all NZTA involved parties to quickly and simply visualise aspects of decision making that require improvement. The vulnerability matrix would be also useful to set formal standards and benchmarks, which will be consistently compared against subsequent experiences and improvements to decision making practices.

D. ***Training package for the decision making board game simulation:*** Ferreira's work (2009) showed that the NZTA can quickly and cost-effectively diagnose how individuals and teams behave under crisis circumstances. Through a decision making board game, SHOs would be able to reveal whether or not staff rely on ad-hoc knowledge to make decisions, and how structured their decision making process is in terms of following pre-defined emergency procedures. The board game package would also be useful to encourage the development and mentoring of leadership, because it will allow junior and senior staff to interact and learn through their experiences. Finally, the board game package would be helpful in establishing a well-structured basis for results discussion.

E. ***Standardising symbols for maps generated during emergencies:*** a set of common symbols and formatting would be created to best suit SHO's response and recovery activities. A training package comprising powerpoint slides and an implementation guide should be prepared for the NZTA;

F. ***Implementation of a GIS-based information sharing framework for emergency response and recovery:*** the lack of proper information technology was one of the problems affecting the achievement of a good level of individual situation awareness and of a good level of training and knowledge. The introduction of GIS-based tools to support the decision making process could considerably increase the individual situation awareness of decision makers. Based on our previous work, we have demonstrated that a proposed SHO information sharing framework would potentially generate NZ$300,000 in travel time savings alone for a South Island desktop case study; and

G. ***Use GIS to support simulation exercises:***during the Exercise "Icarus Flies Again", our research team participated in the activities by producing damage maps as injects were introduced to participants. Based on quick surveys conducted before and after the exercise, it was verified that participants generally demonstrated awareness of the efficiency of GIS technology and confirmed that maps created during an exercise facilitatedecision making and the information sharing processes during an emergency response. GIS technology has demonstrated a number of potential benefits of implementation, e.g. real time mapping which is able to support the decision making process. We envisage that GIS could be an integral part of exercises, because it would contribute a more realistic platform to run exercises.

7 References

AELG (2006). Auckland Engineering Lifeline Group. Lifeline Utility Response Protocols. Working Document 15/05/06. Pp:1-9. Available at www.civildefence.govt.nz. AELG website.

AELG (2005). Auckland Engineering Lifeline Group. Resources Available for Response and Recovery of Lifeline Utilities. Technical Publication No. 282 (Version 1.0). ISBN: 1-877416-02-9. Auckland Regional Council, Auckland, New Zealand.

AELG (2004). Auckland Engineering Lifeline Group Priority Utility Sites. Technical Publication No. 214. ISSN No: 1775-201X. ISBN: 1-877353-18-3. The Librarian, Auckland Regional Council, Auckland, New Zealand.

Alberts, D. S. & Hayes, R. E. (2003). Measurement Hierarchy. *Code of Best Practice for Experimentation*. Washington, DC: CCRP Publication Series

Berroggi, E. G., & Wallace, W. A. (1995).Operational Control of the Transportation of Hazards Materials: An Assessment of Alternative Decision Models. *Management Science*. Vol. 41, No. 12, pp. 1962-1977.

Cheah M., Ngoh C., Fong G., Toh E., (2000). NWC in Action – Experimentation within a Distributed and Integrated Command Environment. *Proc. of 12th International Command and Control Research and Technology Symposium*.

Dantas A., Seville E., & Dharmista G. (2007). *Information Sharing during Emergency Response and Recover: a Framework for Roading Organisations.* Transportation Research Record: Journal of Transportation Research Board. Vol 2022, pp. 21-28; ISSN 0361-1981.

Endsley, M.R. (1995a). *Measurement of situation awareness in dynamic systems*. Human Factors, 37(1), 65-84.

Endsley, M.R. (1995b). *Toward a theory of situation awareness in dynamic system*. Human Factors, 37(1), 32-64.

Ferreira F., Dantas A., Seville E. (2007). Conceptual Dynamic Response Recovery Model for Emergency Events. *Proceeding of the 3rd International Forum on Engineering Decision Making, IFED.* Australia, December 2007. Pp. 61-70.

Ferreira F., Dantas A., Seville E. Giovinazzi, S. (2009*). Extreme Events Decision Making in Transport Networks: A Holistic Approach Using Emergency Scenarios and Decision Making Theory.* Journal of the Eastern Asia Society for Transportation Studies (in press).

Ferreira, F. (2010). Dynamic Response Recovery Tool for Emergency Response within State Highway Organisations in New Zealand. A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Civil Engineering at the University of Canterbury. University of Canterbury, Christchurch, New Zealand (undergoing).

Fink, S. (1986). *Crisis Management: Planning for the Inevitable*. American Management Association, New York.

Fredholm, L. (1999). *Emergency Management as Co-ordinated Cognitive Modelling on Different Time-scales.* Department of Fire Engineering, Lund University, Sweden. Report 311. ISSN: 1402-3504.

Mendonça, D. and W. A. Wallace (2007). *A Cognitive Model of Improvisation in Emergency Management*. IEEE Systems, Man and Cybernetics: Part A, 37(4) 547 – 561.

Mendonça D., Beroggi G. E.G., van Gent D. Wallace W. A., (2006). *Designing gaming simulations for the assessment of group decision support systems in emergency response.* Safety Science. Vol. 44, pp. 523–535.

Mendonça, D. (2005). *Decision Support for Improvisation in Response to Extreme Events: Learning from the Response to the 2001 World Trade Center Attack*. Decision Support Systems. Vol. 43, pp: 952-967. Elsevier Ltd Editor.

Mendonça, D., Beroggi, G.E.G., Wallace, W.A., (2001). *Decision support for improvisation during emergency response operations.* International Journal of Emergency Management 1 (1), 30–38.

Sinha, R. (2005). *Impact of Experience on Decision Making in Emergency Situation*. C/D Extended Essay. Lulea University of Technology. Department of Human Work Science. Division of Engineering Psychology. Sweden. ISSN: 1402-1781.

TNZ (2000). Transit New Zealand contractual documents, State Highway Emergency Procedure and Contingency Plan. Region 2.

Vedder, R. G. (1990). *Expert Systems for Crisis Management: The HIT Project.* in Expert Systems for Business and Management. Edited by Jay Liebowitz. Prentice-Hall. ISBN 0-13-296468-6. pp.

Zografos, K. G. Vasilakis, G. M. Giannouli, I. M. (2000). *Methodological framework for developing decision support systems DSS for hazardous materials emergency response operations*. Journal of Hazardous Materials 71, pp. 503–521. Elsevier.

ANNEX A – ICARUS EXERCISE SCENE SETTER AND TIMETABLE/INJECTS

A-1 – Scenario Scene Setter.
Source: Exercise Icarus Planning Document, 2007 (Version 3) .

This scenario is based on that used for the Capital Quake exercise in November 06, with some modifications.

At 4pm on the 21st of November, a major shallow earthquake measuring 7.6 on the Richter scale occurs with the epicentre located at Petone. The earthquake creates a 75 kilometre surface rupture along the Wellington Fault from Cook Strait to Kaitoke north of Upper Hutt. Along the fault the ground is displaced horizontally by up to 5 metres and vertically by up to 1 metre. Severe ground shaking occurs for at least 45 seconds in the Wellington/Hutt Valley basin, and sedimentary areas over a 100-kilometre radius amplifies ground shaking for varying periods.

The earthquake results in Modified Mercalli Intensity (MMI) shaking of 10 in the vicinity of Petone and the Wellington CBD, and MMI shaking of 9 in much of the rest of the Wellington city area (see below diagrams and definitions). Regions from Nelson to the Wairarapa also receive significant shaking, but damage levels are less severe than those in the Wellington region.

Major damage is caused to infrastructure of Wellington, Hutt Valley, Porirua and Kapiti areas. Several buildings collapsed and many tonnes of debris and glass are covering inner CBD streets. The violent horizontal and vertical motions that lasted for about one minute also caused widespread liquefaction and slumping in Wellington City, Hutt and Porirua.

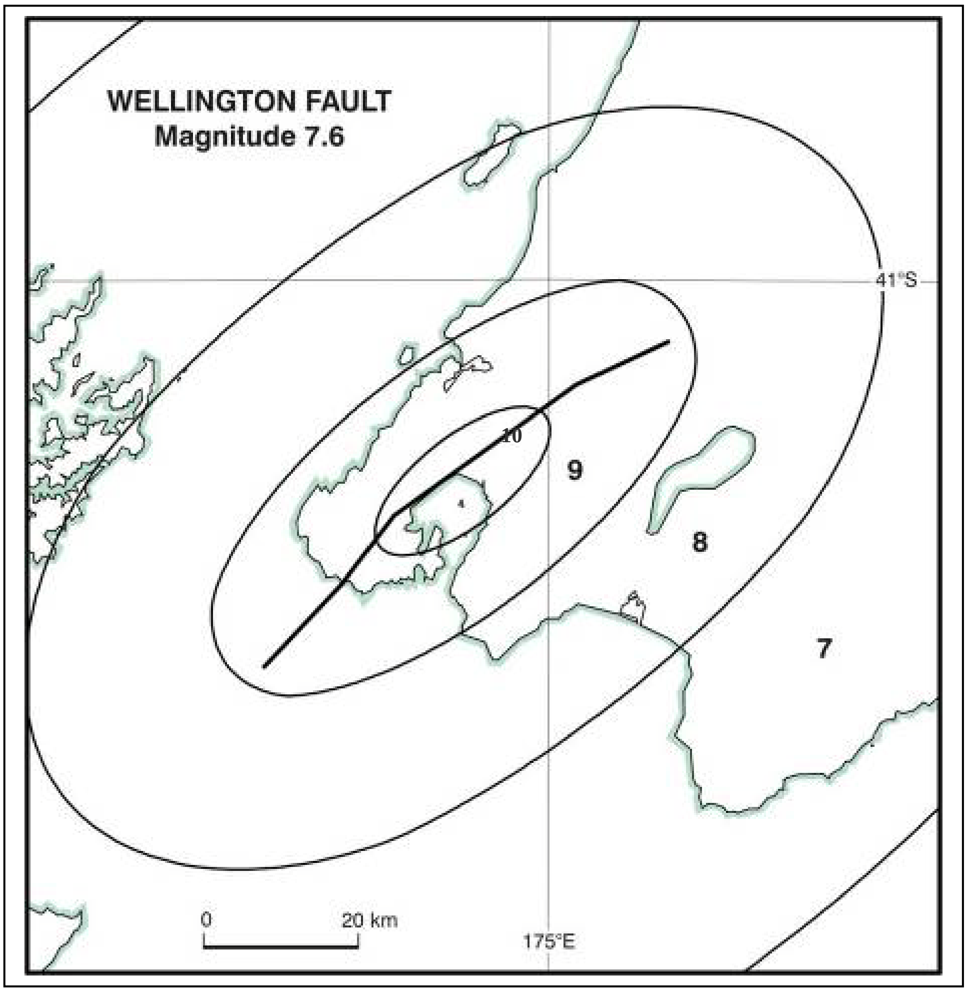
Consequences from the impact include:

- Collapsed buildings – trapped people
- Many people injured/dead
- Road access blocked – cities/districts isolated
- Lifeline services severely damaged/destroyed
- Fires following the earthquake
- Scarce resources - human, equipment, material

Severe damage occurred around the harbour perimeter due to liquefaction, and the Wellington CBD and the wharves in the harbour were severely damaged. In this scenario, the earthquake only caused minor seiching in the harbour and early tsunami warnings were lifted about three hours after the initial earthquake event.

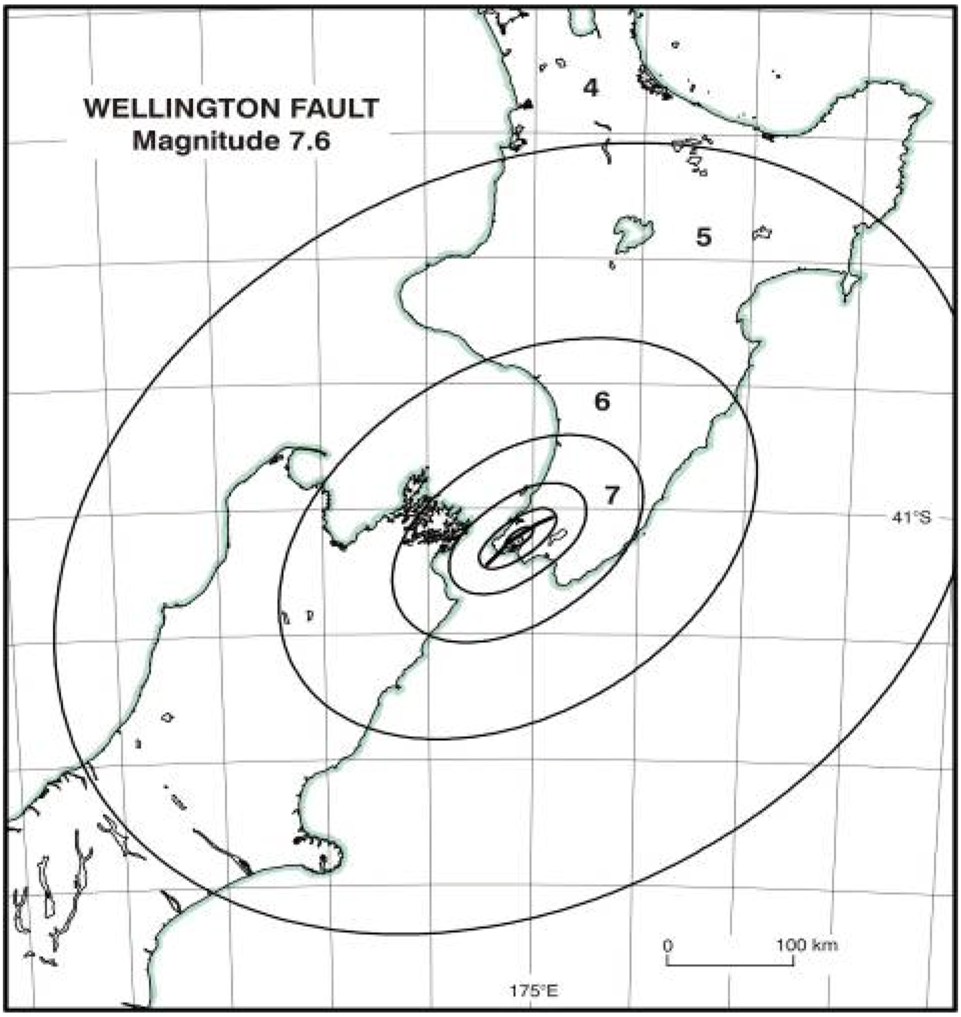
Although the impacts from a Wellington fault event will cause significant damage to the physical and built environment, it is important to realise that many structures will sustain only minor or moderate damage. For example, loss modelling indicates that approximately 11% of houses across the Wellington region would be severely damaged or would collapse.

Aftershocks of varying magnitudes from M6.5 to smaller M5.5 are expected to continue for many days, weeks, and even months.



MM10	• Most heavy structures extensively damaged; some well-built timber structures destroyed • Landsliding very widespread in susceptible terrain, including failures of roads and rail cuttings; liquefaction effects widespread and severe
MM9	• Considerable damage in specially designed structures; extensive with partial collapse in ordinary buildings. Underground pipes broken • Landsliding general on steep slopes; liquefaction effects widespread with large lateral spreading adjacent to rivers and ports

Figure A1.1 Modified Mercalli Intensities: Scale of Damage in Wellington Region



MM8	• Slight damage in specially designed structures; considerable in ordinary buildings and great in poorly built structures • Small to moderate landslides (10^3 to 10^5 m^3) widespread; a few large landslides (10^5 to 10^6 m^3). Evidence of soil liquefaction (sand boils, lateral spreading and settlement)
MM7	• Negligible damage in buildings of good design and construction; considerable in poorly built structures • A few small to moderate landslides (10^3 to 10^5 m^3)
MM6	• Felt by all; damage slight • A few small soil and rock falls
MM5	• Felt by nearly everyone; unstable objects overturned
MM4	• Felt indoors by many; outdoors by few

Figure A1.2 Modified Mercalli Intensities: Scale of Damage in Wellington Region

Table A1.1. Exercise Timetable and Injects.

TIME	INJECT
8am	All players get a phone call from a control team member advising them: to review their personal preparedness at home; consider how long it might take to get to the EOC in a real event; fill a backpack with what they might take to the EOC in a real event and to report to the nominated EOC location by 9am
9am - NZTA	Mock handover briefing, where players are briefed on the scenario, – including the exercise simplification of focusing all efforts on reopening SH1. They will also have the suggested EOC layout and information management systems explained to them. This briefing is expected to take 20mins.
9am - FH	Activate and set up EOC. Initial briefing to players on the scenario – including the exercise simplification of focusing all efforts on reopening SH1.
9am - GWRC	Activate EOC. Initial briefing to players on the scenario – including the exercise simplification of focusing all efforts on reopening SH1.
9:10am GWRC	*Inject: deliver both DVD and marked up aerial photographs to Lifelines Coordinator.*
9:10am - FH	*Instruction Inject: FH staff are instructed that they need to use actual plant availability information for reopening SH1 - what was on-site at 4pm yesterday. Note: in the exercise context no field crews will be working at this time, so they can only use personal knowledge and any information kept on paper within the office.*
9:20am NZTA	*Inject: players will be told that overnight Richard and Erica sent a runner to GWRC to collect aerial reconnaissance information. Expected time of return unknown.*
9:20am and ongoing - FH	*Injects: Fulton Hogan start to receive piecemeal information from staff as they arrive at the depot on what they have seen on their way from home, and from field crews over the RT. Further injects of this nature will be fed to the FH EOC throughout the morning.*
9:25am	*Major aftershock felt*
9:27am - FH	*Call over RT from FH field crew: "That aftershock just caused a major landslip on Hutt Road just North of Caltex fuel station (just south of Ngauranga Gorge), causing Hutt Road Northbound lane to be blocked. Remaining ground at top of slip appears unstable."*
11:15am - FH	*Inject over RT from FH field crew:We are at [insert name of site of current priority focus] and there look to be a number of fatalities under this debris. Some are still in their vehicles, but other bodies are pretty mangled under the debris. We need to move them if we are going to open the road –we have looked at all the other options, but moving these bodies is really the only option. It isn't going to be a pretty job –some of the bodies are pretty messed up. I haven't seen any Police or anyone in a uniform around here in hours. Are we OK to go ahead and move these bodies –and what should we do with them if we are?*
11:15am - NZTA	Communications Staff arrive at the NZTA EOC: on arrival they are advised that both National Radio and TV1 are rumoured to be in the area and are likely to turn up at the NZTA EOC at any time
11:15 am - FH	*Call from Field Staff over RT: "hey I'm up at Ngauranga Gorge and just wanted to let you know that there is traffic heading North on the South bound lane of the motorway – there haven't been any accidents that I can see yet as people are moving pretty slowly –but it is starting to get quite congested. Just wondering if we should be worrying about traffic management or not?"*
11:30am - FH	*Inject over RT from FH field crew: "We are at [insert name of a likely area]. We are working to get this road cleared, but we have a problem. There is a high pressure pipeline that has been exposed by the slip. We think it is a gas line. If it is still pressurised, I'm worried about sending our excavators too close to it without some advice on how safe it is. If it ruptures it could go like an unsecured fire hose. At the moment we are trying to work around it, but sometime within the next hour we will get to a point where we won't be able to do much more without working right in its vicinity. Before then, can we get hold of the gas company to get some advice on if it is still pressurised?"*

Table A1.1. Exercise Timetable and Injects. (Continued)

11:45AM	TV1 NEWS AND NATIONAL RADIO REPORTERS ARRIVE AT HELSTON ROAD (ACTED BY GLEN AND RICHARD): THEY ARE PRETTY BULSHY AND WANTING INFORMATION!
12:30pm	Exercise ends - Lunch (all sites need to arrange catering)
12:50pm	Hot debrief (20 – 30mins)
As needed –NZTA	*Instruction that a crane is needed at [insert name of site] – NZTA logistics team are to call real suppliers to find out what cranes actually would be in the vicinity if the earthquake happened today*
As needed – if bridge inspections are not being planned.	Phone call from Police: *"Hello, it is Deputy Inspector [insert name] here. Our officers have closed [insert name of bridge not thought to be badly damaged] bridge as we are not sure of its safety – there are some major cracks in the bridge structure and a member of the public is said to have heard it groaning. We are requesting that NZTA send a bridge engineer urgently to verify its safety".*
As needed –NZTA	Facilitators to prompt the discussion about how OPUS engineers will be able to actually get to the bridge sites.
As needed – once OPUS engineer sent to inspect bridges	Bridge damage information to be supplied in the format of marked up bridge photos/plans.

Source: Exercise Icarus Planning Document (2007).

A-2 – Observation of activities at Fulton Hogan EOC

Table A2.1 Fulton Hogan EOC Observation.

Inject Time	Inject Description	Observation Notes
8.00 am	Phone call to participants expecting them to define its personal plans, estimate travel time from home to the EOC and identify gear needs to fill a backpack.	Fulton Hogan staff did not participate in this first hour. Staff were assumed to be at the EOC by the time of the emergency response actions started.
9.00 am	1. EOC set up and active 2. Scenario Briefing / Focus on reopen SH1	After staff had access to the EOC room they start its arrangements as described in the last paragraph in the previous sub-section (Pre Exercise). Also, the emergency box was brought to the room, maps/forms made available on the meeting tables and the desktop computer started.
9.10 am	Damage information as 4.00 pm on the day before (Information only available by personal knowledge and on paper)	The following actions were observed in this phase: 1 – The EOC was still being set up (e.g. flip chart, movable white board, maps, depot role's sign etc); 2 – Emergency Box's items were conveniently arranged on the floor; 3 – Quick meeting in order to organise possible information acquired from the field on the way to the EOC (*Note: just a training simulation of what could happen in a real situation*); 4 – A white board containing information about available gear and staff has been brought to the EOC room (Figure A2.1); and 5 – First damage information collocated on the white board (Figure A2.2).
9.20 am – ongoing	1. Information collected way to depot 2. RT from field crew	1 – It was decided that NZTA is the responsible organisation to define priorities; and 2 – A table with FH's heavy gear (referred as plant by FH's staff) and its respective locations was started to be filled (Figure A2.3).
9.25 am	Major aftershock felt	Andrew simulated the aftershock by turning upside down some tables and disturbing the work environment in the room.
9.27 am	Information by Field crew	1 – Continued to collect information about available gear and respective locations; and 2 – A radio message informing a land slide at Old Hutt Road was almost lost (Figure A2.4).

Table A2.1 Fulton Hogan EOC Observation. (Continued)

Inject Time	Inject Description	Observation Notes
9.30 am	Police radio informing that SH 58 is open and ok to drive	9.30 am – Information that SH 58 was open is collocated on the board; 9.35 am – More information about gear/location is available on the board; 9.37 am – Realised that information about drivers is also necessary. So a new table was started to be filled with information about drivers (Figure A2.5); 9.45 am – Field information is registered on the board as presented in Figure A2.6; 9.47 am – SH 1 damage information well described and organised on the white board (Figure A2.7); 9.50 am – NZTA formally required information about available resources (i.e. gear and personnel). So it was decided to get all possible information about personnel (their location and time to arrive at depots) and gear (which depot they were located); 10.09 am – Fuel availability discussed (Figure A2.8); 10.10 to 10.15 am – Field crew checking gear at Horokiwi and driving south of SH 1; and 10.25 am – Briefing Section I: a quick discussion was conducted. Please refer to section 4 for details.
10.30 am	RT field crew informing that a plant is out of fuel blocking the road	1 – A break was taken from 10.30 to 11.00. This time was used to relax and briefly discuss what could be done to improve the response performance; 2 – This inject was not given at this time; and 3 – FH Crew coming down from Wanganui.
11.00 to 11.15 am	Morning Tea – Discussion time on how to improve the exercise	11.00 am – One team member had to leave the exercise and staff were relocated in its roles considering the discussion prior the break; and 11.00 to 11.15 am – Information on the white board was rearranged in a more organised manner: plant (gear), location, destination, personnel and available personnel (Figure A2.9).
11.15 am	1. Bodies below debris need to be removed – What to do? 2. North traffic on south bond lane – Traffic management?	11.15 am – Required information from NZTA regarding fuel availability and possible locations for delivery; 11.15 am – It was decided to remove bodies after ringing Police and getting an authorization to do so; and 11.15 am – No action was taken regarding traffic management on the motorway.
11.30 am	Cleaning debris near a pressurized pipeline – How to proceed?	11.30 am – First attempt to contact the pipeline company was failed. Subsequent actions: make sure that the location was safe before continuing the work (i.e. pipeline not operational)
11.30 am onwards	A series of injects were provided by Mr. Smith simulating a real scenario.	1 – A few times information from field crew was lost or badly understood; 2 – Communications with NZTA and other organisations (e.g. Gas Company, GWRC) increased considerably; 3 – FH Team had a more coordination on managing communication, information sharing, decision making and resources deployment; and 4 – A series of response behaviours were observed during this phase. Mainly, team had quick response, but it was not done in a structured/organised manner. Response manuals and roles' descriptions were not considered by members.
12.30 pm	End of the Exercise	Summary of damage situation shown in Figure A2.10

Figure A2.1 White Board Containing Available Gear and Personnel.

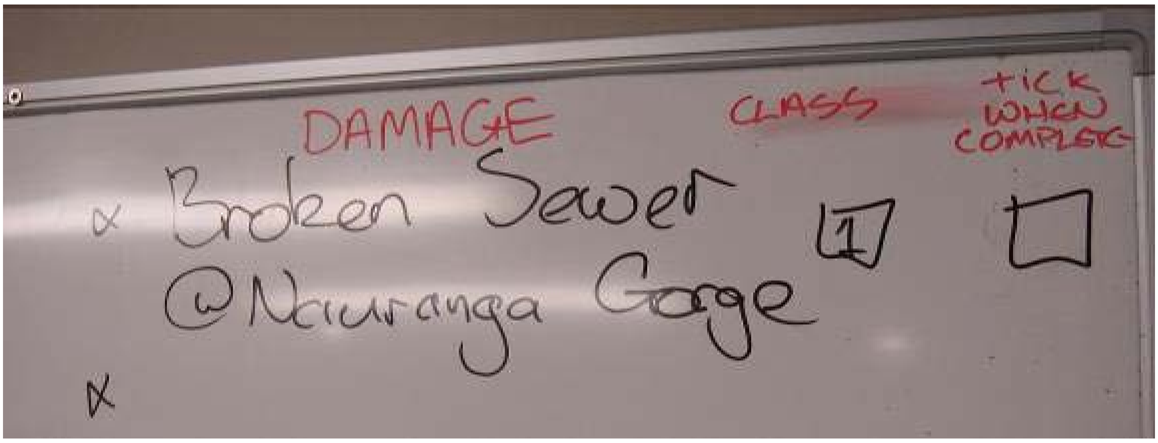


Figure A2.2 First Damage Information.

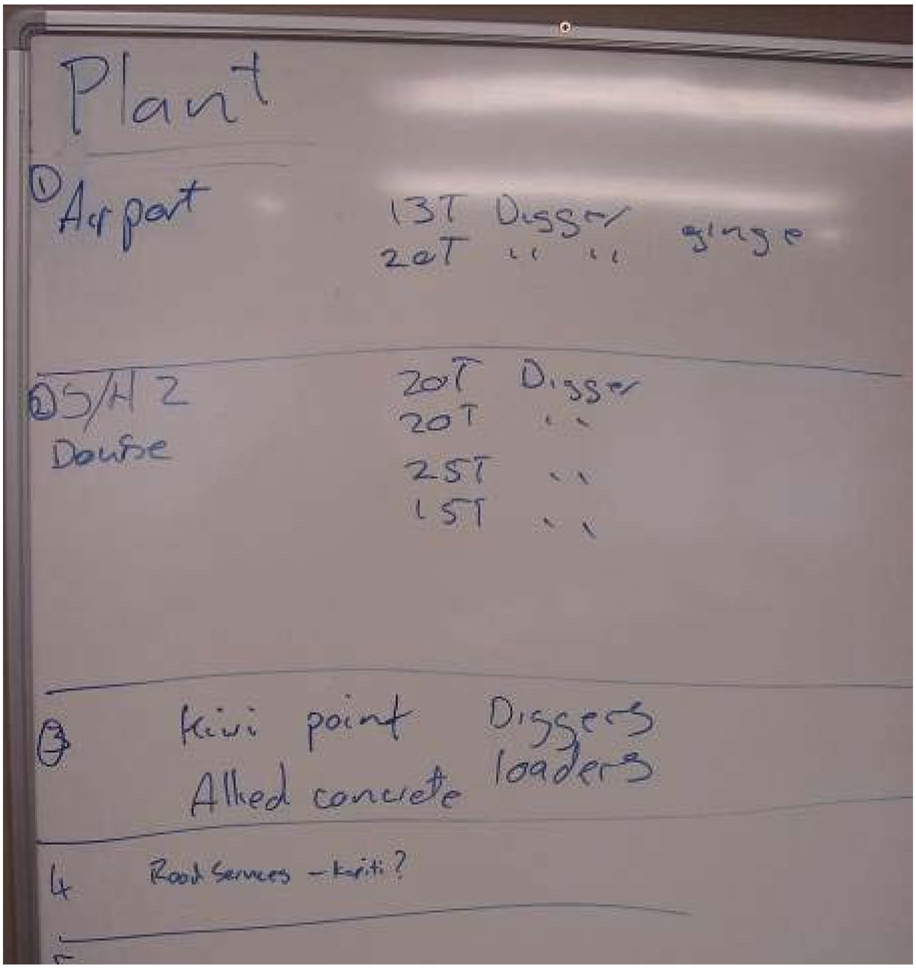


Figure A2.3 Available Gear and Location.

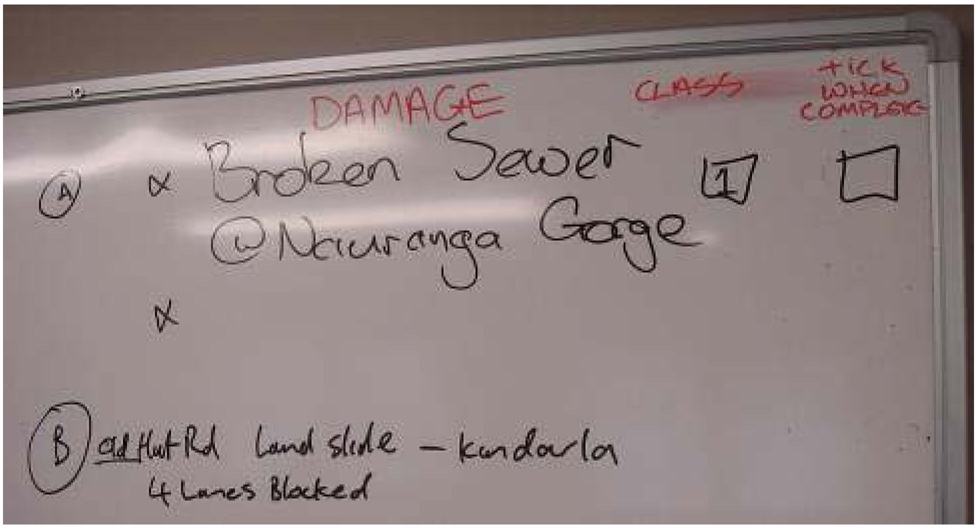


Figure A2.4 New Damage Information as 9.27 am.

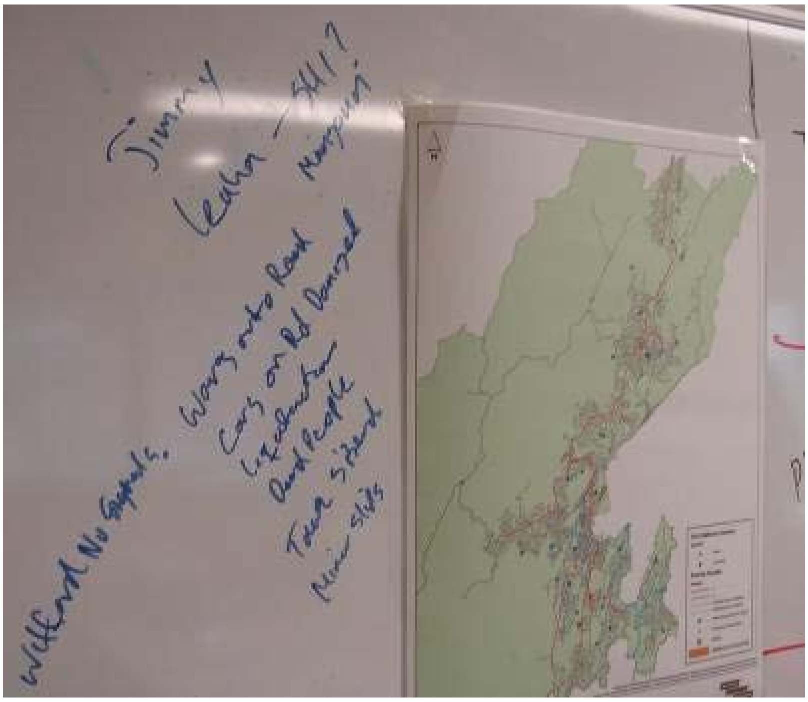


Figure A2.6 New Field Information at 9.45 am.

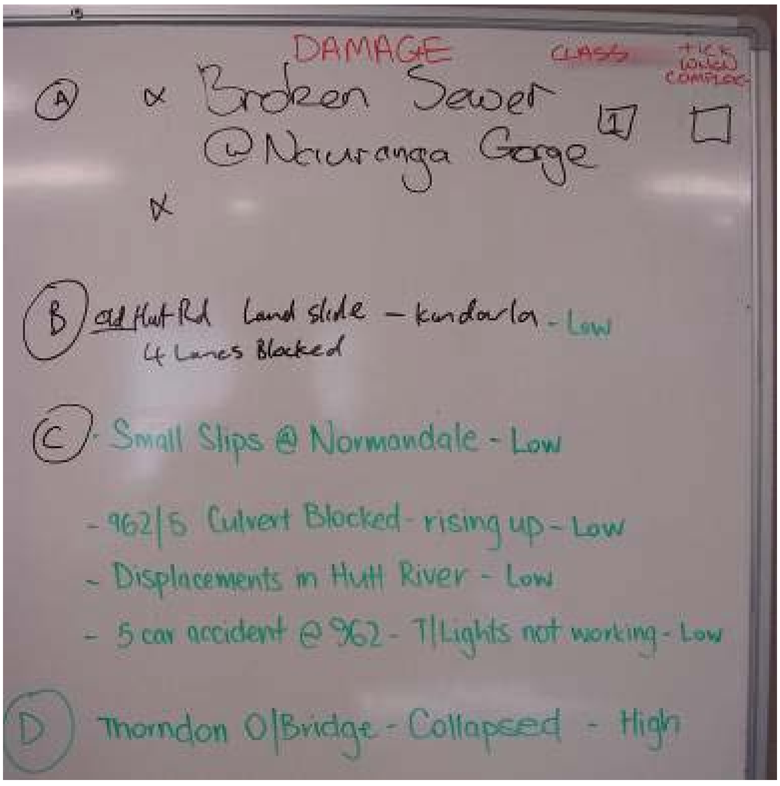


Figure A2.7 Well Described Information for Damage in SH 1.

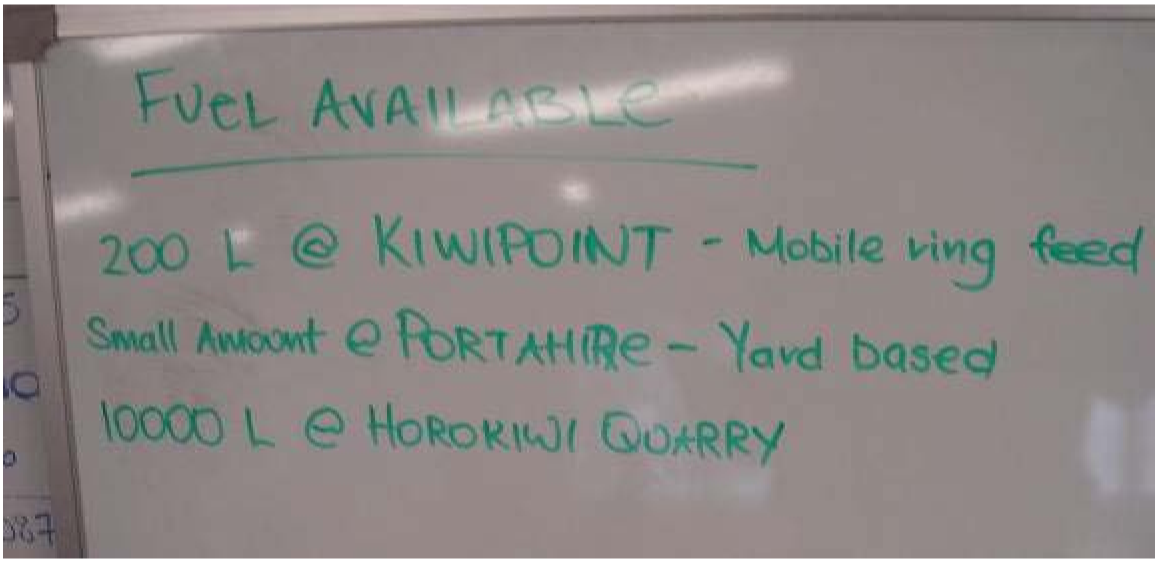


Figure A2.8 Fuel Availability at 10.09 am.

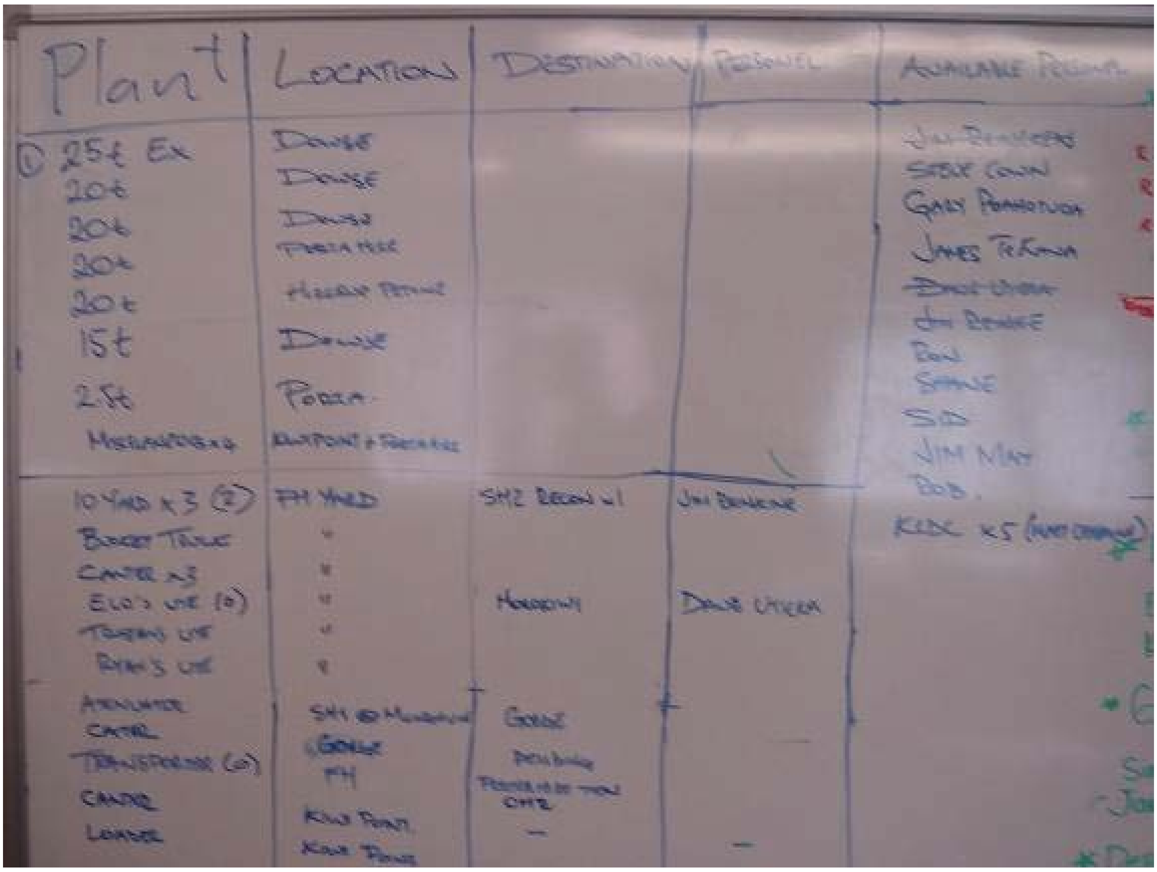


Figure A2.9 Information Rearranged as 11.15 am.

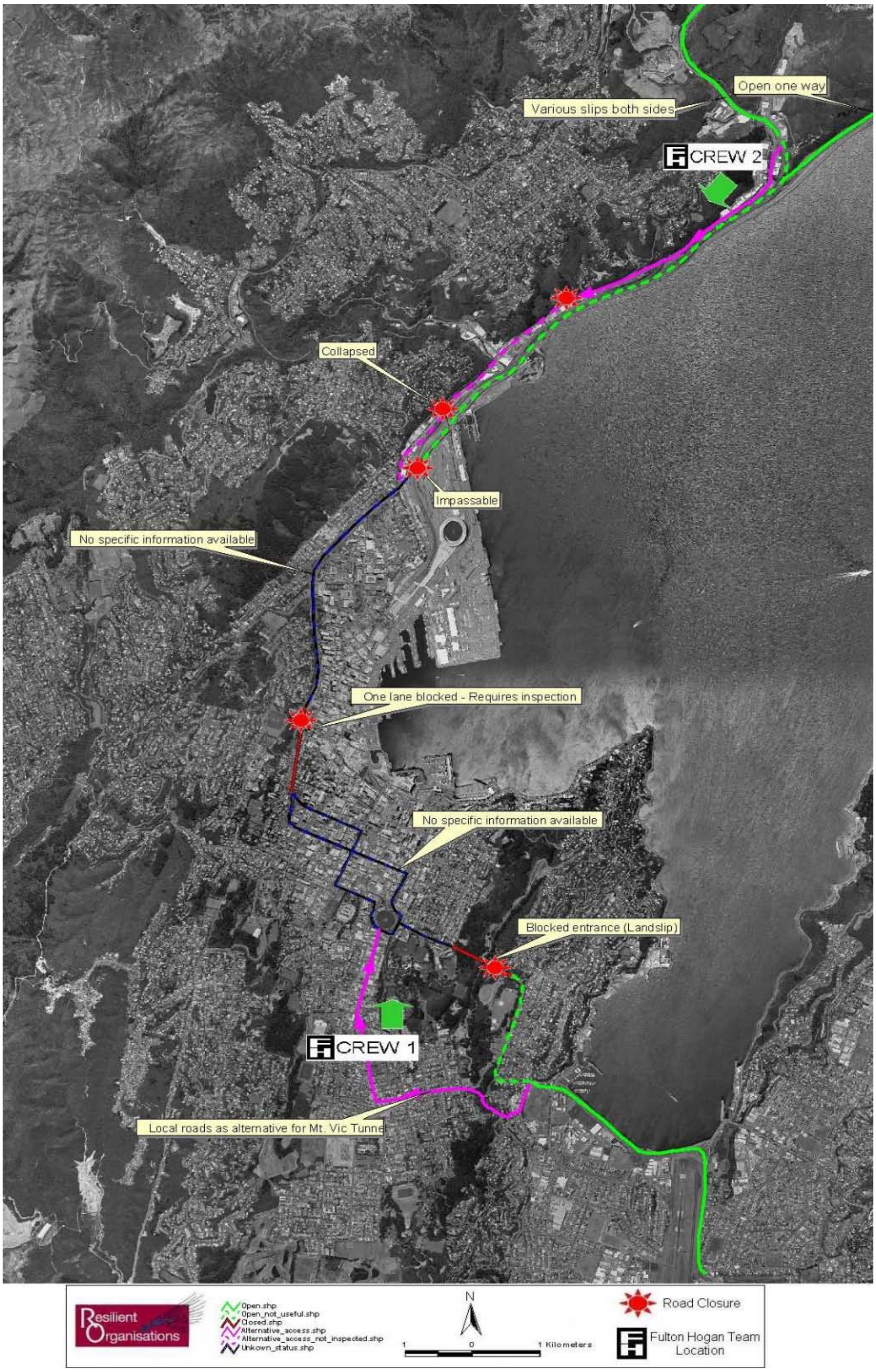


Figure A2.10 Summary of damage situation at 12:30 pm

ANNEX B – Exercise Icarus Hot Debrief Form

Source: Exercise Icarus Planning Document, 2007

Name (optional):
EOC location (organisation):

What did you personally learn from the exercise?

What do you feel worked well?

What do you feel could have been handled better, and how might this be improved in the future?

What would be on your 'wish list' to have available for future response efforts?

Any other comments?

ANNEX C – Capital Quake Exercise Timetable and Injects

TIME	ACTIVITY
1pm 13th Nov	Overall exercise briefing for Controllers. Hannah is going to attend this briefing and share information with the other controllers.
14th November 2006, Tuesday	
5:30am	Earthquake Occurs (no action required for roading orgs)
7am - 7:30am	**FH Petone:** Briefing for FH Petone depot field staff about the exercise, potential impacts of the event, and reminder of their role in responding to the event
7:10am	Inject into main exercise: Phone call from FH to the Police and NZTA regional office: "A number of massive landslides have occurred along Centennial Highway (SH1 Pukerua Bay to Paekakariki). Some workers trapped please send rescue teams"
10:30am	Injects to be provided to both NZTA National office and WCC about plant availability and location around the Wellington region. These injects to be developed from FH Petone field staff briefing.
Mid-morning	Contact to be established between WIAL and Fulton Hogan regarding restoration of the airport runway. Arrangements put in place for a meeting involving WIAL, FH and BECA pavement engineers at 9:30am on Day 2.
12pm – 12:30pm	**FH Rongatai:** Similar briefing for FH Rongatai depot staff.
2:30pm	Injects to be provided to both NZTA National office and WCC about plant availability and location in the central city. These injects to be developed from FH Petone field staff briefing.
3pm – 4:30pm	**All participants:** Briefing for all staff involved in the exercise from a roading perspective at MWH's offices. This briefing will set the scene for the exercise including showing a video on what a Wellington Quake might actually be like to experience and images from Thailand showing the damage caused by resulting tsunami. This will be the context for discussions around personal and family preparedness and the challenges of getting to the EOC. This scene setter will also include a briefing about how the exercise will work (the rules of the game) and show an edited video of the Einstein exercise. *INJECT: latest situation report from the Capital Quake Exercise*
4:30pm – 5pm	**EOC Managers:** After the larger briefing, each organisation will have their own mini briefing for players in terms of what is expected to be achieved during the exercise.
7pm	End of Day 1 controllers briefing: There is a general exercise briefing for all controllers to recap on how Day 1 went. Erica will attend this, as well as the student observers, and can let the other controllers know of any significant information or changes required.

ANNEX C – CAPITAL QUAKE EXERISE TIMETABLE AND INJECTS (Continued)

TIME	ACTIVITY
15th November 2006, Wednesday	
7am	*INJECT: All staff involved in the exercise will receive a phone call from their respective controllers (i.e. Vic will call FH Petone team etc) to advise the locations where their respective EOC's are going to be set up.*
7:30am – 9:30am	**Each EOC:** Staff starting to arrive and set up the EOC. Roles assigned. Communications established between EOC's and with Civil Defence. *INJECT: as soon as comms with CDEM established, Reconnaissance Report will be given.* *INJECT: media reports of damage.* Information starts to flow into the EOC's in terms of the regional aerial reconnaissance reports, staff observations, media reports, and information sharing between EOC's. This information needs to be collated into a meaningful picture of overall damage. Planning of flying routes for further reconnaissance missions. *INJECT: Damage Observed forms filled out be FH staff provided to FH EOC's* *INJECT: RT's calling in with damage observations* *INJECT: media reports of damage.* (NOTE: Some of the above injects will be conflicting!) *INJECT: staff availability and plant location forms filled out by FH staff to be provided to FH EOC's* *INJECT: Media representatives calling for information* *INJECT: Civil Defence and Transport Cluster request report on road status at 10:30am*
9:30am	**Any EOC's with FH radios:** Open channel call to provide a regional status update. This report will be done over the actual open channel, and all field staff are encouraged to listen in.
9:30am – 11:30am	**WIAL:** Meeting between WIAL EOC, Fulton Hogan and BECA pavement engineers to evaluate damage to the runway, repair options, resource requirements and expected restoration times.
10:30am	Report required to Civil Defence and Transport Cluster on the current status of the road network. More detailed reconnaissance missions. Request CAA to use helicopter for reconnaissance. *INJECT: requests from CDEM for an updated report on road network status, this time including estimated time to reopen roads by 12pm*
11:30am – 12:30	Lunch on the run!
10:30 – 12pm	**All EOC's** Continuing to build up a picture of damage and available resources, to establish road clearing priorities and develop a road access plan with estimated times till restoration *INJECTS: information coming back from reconnaissance missions* *INJECT: requests from local CDEM office for shifting priorities* *INJECT: severe fuel shortages* *INJECT: large aftershocks* *INJECT: Media reports of another contracting team being hurt in an aftershock causing further landslides; unclear if it is a FH team or not* *INJECT: Media calling FH Corporate demanding information INJECT: Media arriving at NZTA and FH Petone EOC's demanding information/interviews*
12pm – 12:30pm	Report required to Civil Defence and Transport Cluster on status of the road network, operational priorities, estimated times for restoring access on each route, and an detailed list of looming issues and resource constraints
12:30 – 2pm	**Tour:** Visits to the NCMC (the national EOC under the beehive) and/or the Wellington Region CDEM EOC's to see them in action. Tour starting at the NCMC at 1pm.
2:30pm	**MWH:** Hot wash debrief on the exercise (plus social drinks?)

ANNEX D – Observed Vulnerabilities in Simulation Exercises

Table D.1 - Vulnerabilities affecting the Physical Domain during simulation exercises.

PHYSICAL DOMAIN
Deployment of physical and human resources
- Decision-makers not entirely sure on the range of available options; - Impossibility to optimise the deployment of physical and human resources due to the very limited options; - Problems in localising physical resources before and after their deployment; - Staff roster not implemented; - Lack of shelter, food, water to support the massive evacuation of people; - Insufficient fuel and extra vehicles to evacuate people.
Temporary traffic management
- No traffic modelling implemented to understand possible traffic scenarios; - Lack of a comprehensive awareness of the traffic situation during the emergency and response phases.

Table D.2 - Vulnerabilities affecting the Cognitive Domain during simulation exercises.

COGNITIVE DOMAIN
Individual Situation Awareness
- Staff not fully aware of their role and duties; - Lack of awareness about the evolving scenario (e.g. consequences, affected areas, impact on traffic behaviour); - Lack of understanding on the dimension and criticality of the event; - Lack of awareness about available personnel and assets.
Level of Training and Experience
- No traffic modelling implemented to understand possible traffic scenarios; - Lack of a comprehensive awareness of the traffic situation during the emergency and response phases; - Absence of decision making supporting tools for enhancing knowledge management - Individual skills seldom used in their fully capability; - Lack of training on available knowledge on vulnerability and risk analysis. These could support the scenario perception, the understanding of needs and criticalities and the future projection of the evolving situation.
Intangibles of leadership and unit cohesion
- personnel not associated to suitable roles considering their particular skills - passive role during the exercise; - reluctance to get involved and be proactive

ANNEX D – OBSERVED VULNERABILITIES IN SIMULATION EXERCISES (Continued)

Table D.3- Vulnerabilities affecting the Information Domain during simulation exercises.

INFORMATION DOMAIN

Connectivity

- Lack of emergency back-up generators;
- Potential difficulties to have access to the information due to power outage;
- No ideas about possible alternatives in case of phone and telecommunication unavailability;
- Radio connection with consultants not always working;
- Information about available resources not well shared between contractors office and field personnel and between contractors office and NZTA;
- Lack of TV and radio in the emergency room. Lack of awareness of the information that media were realising to the public
- Communication by e mail inefficient and delayed many times;
- Contractors not always receiving NZTA email;
- Excessive size of the email attachments;
- Lack of a consistent email protocol for emergency response;
- No shift to phone when e-mail miscommunications was noticed;
- Lack of assigned personnel to collect, share and process data and info;
- One person only dedicated to answer the call, few missed calls.;
- Lack of a dedicated terminal for each one of the decision maker for accessing information.

Information Richness

- Use of non-codified abbreviations and symbols;
- Too much use of acronyms, some unnecessary and misleading;
- Information summary on the laminated map and board insufficient and inaccurate to allow for a clear representation of the evolving scenario;
- Absence of agreed templates/rules for collecting data and information;
- Lack of an organised manner to record and update information;
- Existing forms for collecting data and information inadequate;
- Use of a same situation report along all the exercise, difficulties in identifying changes in the situation.
- Very poor use of information technology (including GIS system) to collect, analyse and share information;
- Lack of the specific knowledge to manage and process properly the information acquired.

Information Reach

- Office staff had problems in identifying locations and activities of the field crews;
- Difficulties in transferring/ explaining actions and information from the NZTA National Office CDEM and operations rooms;
- Lack of information selectivity: impossibility to restrict information access to some of the staff in order to force them to perform only tasks associated to their roles;
- Limited efforts to disseminate the compiled information to other organisations
- Poor and disorganised information sharing, performed with limited continuity.
- Confused priority identification;
- Very strong concerns in releasing information to media

ANNEX E – Observed Vulnerabilities in Real Events

Table E.1 - Vulnerabilities affecting the Physical Domain during real events.

PHYSICAL DOMAIN
Deployment of physical and human resources
- Different location of human and physical resources on respect to incident area; - Non suitable gear for operating during the night because batteries for the spotlights available were faulty - Lack of knowledge about the location and prior characteristic of roading element
Temporary traffic management
- Lack of redundancy in the network; - Difficulties in transporting equipment and personnel in order to effect repairs because of the road temporary closures; - Alternative routes through mountainous not used causing delays in the response actions.

Table E.2 - Vulnerabilities affecting the Information Domain during real events.

INFORMATION DOMAIN
Connectivity
- Communication entirely dependent on internet and phone - Lack of alternative ways of communication - Very poor coverage of Vodafone cell phone in some area - Lack of flexibility in the information chain. - Only one person retains all the exchanged info
Information Richness
- Lack of an organised manner to record and share info - Lack of a standardised ways to receive, log and update information - Limited used of Information technologies capabilities (only RAMM Data Base and a video record of the network) - The information system used (RAMM) was perceived as not suitable for coping with the dynamic nature of crisis event.
Information Reach
- No matching info between organisations (police and contractor)